THE COST BENEFITS OF ALTERNATIVE LOGISTICAL SOLUTIONS IN A CONSTRUCTION PROCESS.

A costing model to predict the cost benefits of Construction Consolidation Centres during the preparation stage of a construction project within the Dutch construction sector.

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FOREWORD

This thesis contains the research I conducted to finish the master Management in the Built Environment (MBE) at the University of Technology in Delft, the Netherlands. The research is part of the Design & Construction Management domain with a focus on managing construction logistics for an improved environment and economic performance.

Inner-city construction sites fascinate me since I was young. Huge cranes, dozens of construction workers walking around, and trucks bringing new materials every day, all contributing to a new building. It was clear that I wanted to contribute to this process of developing buildings and creating new places for people. During my studies, I learned about the necessity to improve these processes. Creating less waste, reducing the impact on the environment, and making smarter use of the limited labour workforce are only a few examples. While searching for a graduation topic I heard about the impact smart logistics could have on the processes of the construction industry. The development of Construction Consolidation Centres is one innovation related to the logistical process of construction projects. Contributing to the knowledge of these innovations formed the motivation for this research. I hope these innovative processes will turn into standard practice in the near future to finally utilize their full potential.

I would like to thank the following people and organisations that helped me during this research: Ruben Vrijhoef and Peter de Jong my main mentors for their support and professional guidance during this research period. Volkerwessels Bouwmaterieel and especially the colleagues at Bouwhub Utrecht for their input from practice and their guidance during my internship. All experts involved in the Wonderwoods project who provided information and their professional opinions on the topic. Further, my friends, fellow students and family for supporting me during the graduation process. A special thanks to my parents, brother and girlfriend for their unconditional support in everything I do.

Dear reader, I hope you will enjoy reading this report and gain some new insights.

Kind regards,

Ivo Agricola

1. INTRODUCTION

Over the past years, construction activities in the Netherlands shifted from spacious greenfield developments to dense inner-city redevelopment projects. Approximately 50 per cent of the total turnover in construction is generated within the country's large cities. It's expected that this percentage will grow to 80 per cent in the near future(De Bes et al., 2018). Inner-city construction activities and the large logistical supply stream connected to it has a large impact on the liveability of the city. Almost 30 per cent of al business traffic is related to construction logistics (Vrijhoef, 2018). Consequences of these activities are a nuisance for neighbours due to noise, congestion, poor air quality due to the emission of greenhouse gasses and particulate matter, and a negative impact on road safety (De Bes et al., 2018) (Vrijhoef, 2018).

The development of Construction Consolidation Centres is an innovation in the logistical process that helps with lowering the impact construction has on the cities. As can be seen in Figure 1 the process of transport to the construction site is changing from direct transport to construction site towards transport to a location in the periphery of the city and bundled transport from this location towards the construction site.

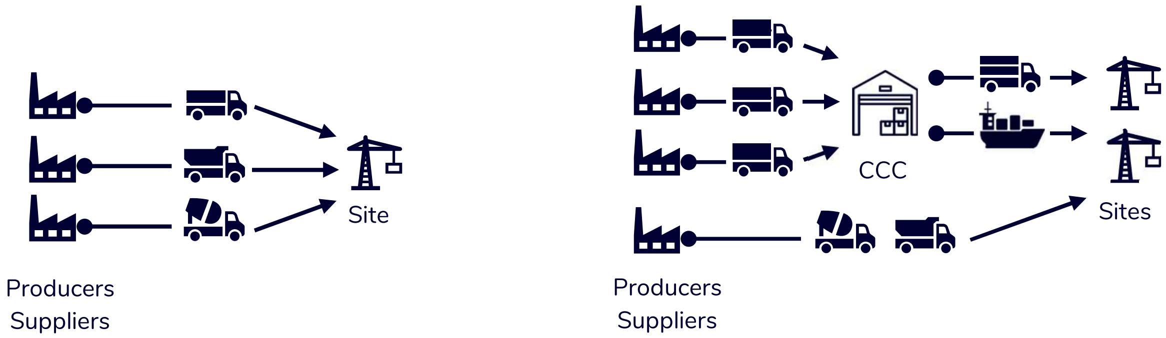

Figure 1 Traditional construction logistics process and process including a CCC.

The benefits for society and involved companies would suggest that the CCCs are a great success and are widely used in practice, the reality is different. Researchers debate the ability of CCCs to be financially self-sufficient (Browne et al., 2007) or state that the implementation of CCCs in the construction process is expected to increase when the financial benefits are transparent. De Bes et al. (2018) stress the need for the development of financial models that enable supply chain partners to consciously decide for the implementation of Construction Consolidation Centres based on predicted financial benefits. An important step in the development of these new logistics solutions is proving their value by measuring the impact on efficiency and costs (De Bes et al., 2018). These statements in literature formed the base for this research and led to the following problem statement.

Problem statement

The implementation of Construction Consolidation Centres in the Dutch construction sector is limited due to a lack of tools to prove the financial benefits. A calculation model that predicts the impact of the logistical costs on the construction costs in the preparation stage of the project to prove the financial benefits of the Construction Consolidation Centres has not been developed yet.

Aim

The aim of this research is to develop an alternative model for cost accounting in the construction industry. This model includes the activities of the construction logistics process impacted by the implementation of a Construction Consolidation Centre. The developed model needs to enable the prediction of the impact of the implementation of a CCC on the costs of a construction project in the preparation stage of the process.

2. RELEVANCE

Scientific relevance

This research is based on a gap in the literature. Previous research has indicated the benefits of implementing Construction Consolidation Centres in construction projects within the Dutch construction sector. Research on the impact of implementing the CCC on the financial performance of a construction project has not yet resulted in financial models for cost accounting (De Bes et al., 2018).

The scientific relevance of the conducted research is two-folded. The developed model is a new step towards a calculation model that can predict the impact of implementing a Construction Consolidation Centre in the supply chain of a construction project in the Dutch construction sector. With this result, it contributes to bridging the gap between measuring successful experiments as was done by (De Bes et al., 2018) and actual implementation of the new methods. De Bes et al. (2018) stressed the need for a model that provides insight into the cost-effectiveness of innovative solutions. The developed model contributes to these insights and provides a conversation starter for a new division of revenues within the supply chain.

A second contribution of the conducted research is to the field of activity-based costing as described in the paper of Yuan Fang and Thomas Ng (2011). They stressed the need to test their framework for analysing construction logistics with experts from contractors and suppliers in a real estate project. This research proved that a selection of the developed framework could indeed contribute to tracing back the consuming activities. The framework contributed to predicting the impact of implementing new activities like the construction consolidation centre to the construction process. Tracing the consumption back to a cost element, however, proved to be difficult in the early phase of the preparation stage of construction projects analysed in this research. Validation of the developed model with the experts involved in the construction project increased the understanding of the applicability of this method for cost accounting in this early stage of the project.

Social relevance

The implementation of Construction Consolidation Centres has a number of positive effects on society. The first aspect includes a reduction in freight transport in the cities which reduces:

- Traffic jams
- Noise
- Air pollution

Apart from the reduction of nuisance in the cities. The implementation of the CCC reduces the number of construction materials that get damaged, lost, stolen and over-ordered compared to the typical process.

- Fewer materials used
- Less impact on the limited resources on earth

The CCC ads a wide range of value-adding logistical service activities and contributes to the performance of the construction industry. The innovations have a positive contribution to labour productivity on-site which in turn helps with the challenges the construction industry is facing.

- Increased labour productivity
- Less emission
- Increased production capacity

Proving the exact relationship between this research and increased implementation of CCCs is difficult. The developed model and the results of implementing the CCC in this research, however, illustrate the impact that could be made. The reduction in transport to the construction site will lower the impact the construction sector has on the environment and the cities. Which by itself should be an extra motivation for professionals working in the construction industry to at least consider implementing these innovations in future projects.

3. QUESTIONS & METHODS

This research answers the following research questions:

Research question

To what extent can the logistical costs related to construction be modelled in the preparation stage of a project to predict the impact of the implementation of a Construction Consolidation Centre?

Research sub-questions

1. Which definitions and aspects of construction logistics need to be included in the model?
2. Which information should be available in the preparation stage of the project to provide input for the model and which generic cost data can be used?
3. How to accurately model and predict the financial impact of using a Construction Consolidation Centre in a new costing model?
4. What Output should be generated by the model to create added value in the preparation stage of the project?
5. Which conditional factors determine the implementation of the model?

Methods

This research is conducted through the following research methods.

- **Literature review** - A literature review is used to analyse the activities that are part of the construction logistics process including the Construction Consolidation Centres. A better understanding of the CCC is developed by analysing the history, the typologies and the benefits of a CCC. The second part of the literature review includes the methods for cost accounting. An extensive analysis of the available methods, cost types included and applicability for construction logistics is conducted. The studies combined formed the theoretical framework used in this empirical part of this research.

- **Interviews** - By means of interviews with the operator of CCC Utrecht the initial framework is developed towards a calculation model. The interviews and documents provided by the operator are used for the development of the model. The aspects included in the model are tested with the available experience-based data provided by the operator of the CCC.

- **Case study** - The developed model is tested in the Wonderwoods project. By applying the model as a participant in the project to the data set provided by the contractor the applicability of the model could be tested. The factors that influence implementation could be analysed and the output of the model could be applied.

- **Expert panel** - In an online survey, the experts involved in the Wonderwoods case were asked to give their professional opinion on the developed model. To validate the model that is tested the participants were asked to react on five statements. The activities included in the model that could not be tested in the Wonderwoods project are discussed with the participant by means of another five statements.

4. LITERATURE REVIEW

A selection of the most import findings in the literature review for the development of the model is presented in this paragraph.

Construction Consolidation Centres

The activities conducted at a CCC are listed below an explanation of all activities can be found in paragraph 3 of chapter 4.

- Logistics coordination
- Prefabrication
- Waste transport
- Just-in-time delivery
- Warehousing
- Shuttle service
- Buffer storage
- Site logistics
- Express transport
- Day production packages

A selection of the benefits of Construction Consolidation Centres found in literature is listed below.

Transport

- Reduced vehicle movements and distance travelled by improving load factors and reducing empty running
- Increased reliability of the deliveries (on time and right place, and in line with agreements)
- More flexibility and punctuality of the deliveries
- Efficient use of vertical transport materials on site (due to using in of-hours)
- Reduced waiting times before unloading on-site
- Reduced unloading times on site
- Opportunity to use clean vehicles on roads or transport on water
- Opportunity to combine waste transport with deliveries

Service by CCC

- Materials are stored in a secured location.
- Insight into stock for deliveries to site
- One contact for delivery of materials to the site
- Flexible response to express orders
- Opportunity to prefabricate

On-site

- Less storage capacity required on the construction site
- Reduced handling of materials on-site results in less damage to materials
- Increase in on-site productivity as a result of less labour downtime
- Reduction in accidents as a result of cleaner and safer work environments

Environmental

- Reduction in number of kilometres driven by trucks
- Reduction in emission, noise and pollution in city centres
- Reduction of the congestion problems near the construction site
- Reduction in materials used due to less damaged and stolen materials
- Reduction in the over-ordering of materials

Cost accounting

The second aspect included in the literature review is an analysis of available methods for cost accounting in construction and a selection of the types of cost included in the activities. The framework developed by Yuan Fang and Thomas Ng (2011) is used as a starting point for the development of a new model. The framework that is developed for analysing the logistical process of prefabricated concrete walls in a traditional process is adjusted to host the activities of the CCC. The developed framework can be seen in Figure 2. An extensive analysis of the framework and the included factors can be seen in chapter 4.

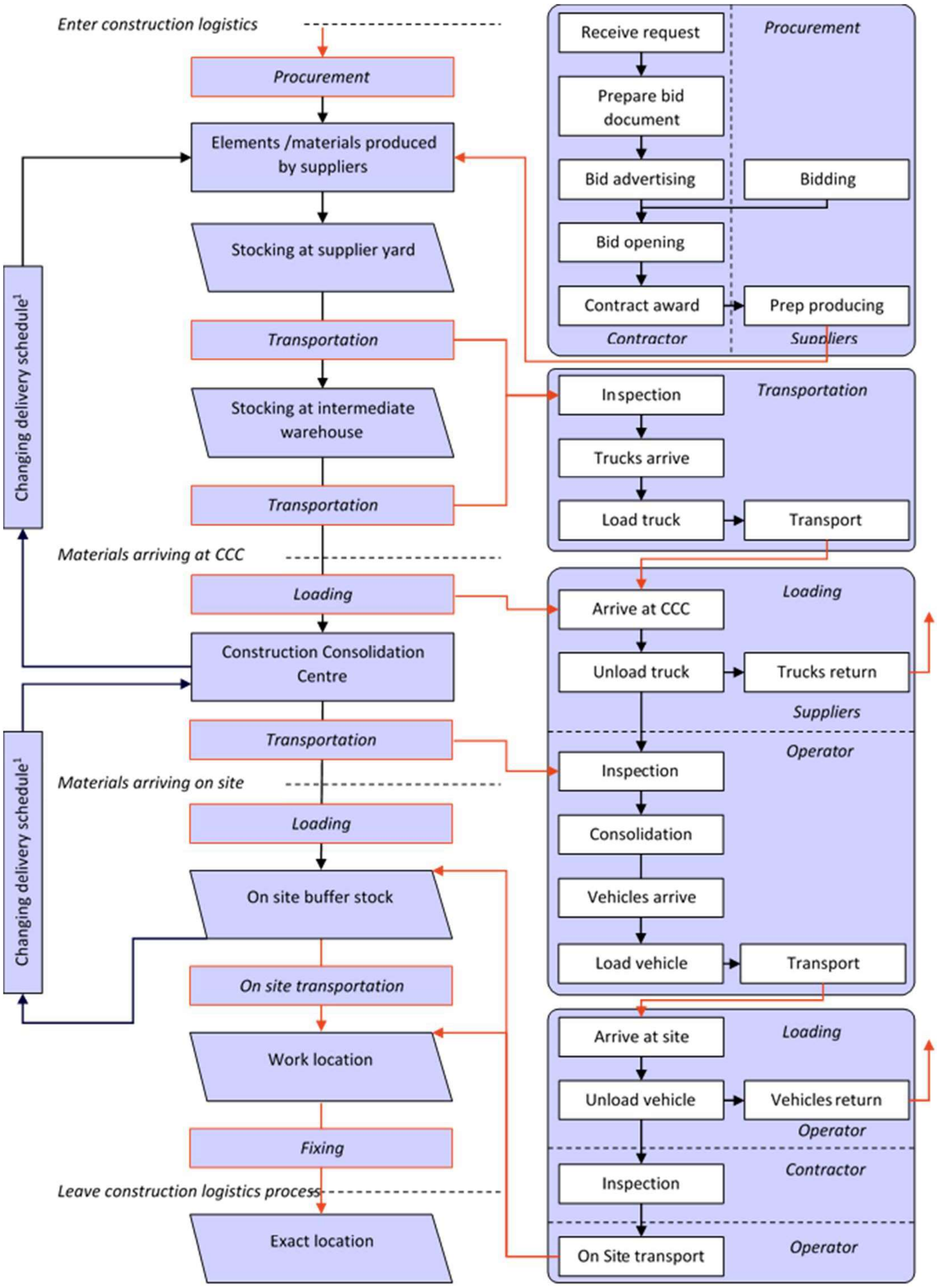

Figure 2 Logistics process and activities of construction material acquisition with CCC (own. illustration based on the model of Yuan Fang and Thomas Ng (2011).

The model that is developed and tested in this research includes activities that are tested on three different levels. The first level of the model contains all activities that are part of the logistical process as explained in the literature. These aspects could potentially be influenced by the implementation of a CCC; however, the aspects are not tested in previous research. These aspects include the costs related to the procurement activities, the process management activities (such as changing delivery schedules) and the costs for stocking at the suppliers' yard or at intermediate warehousing. The impact of implementing a CCC in the process on the costs related to these aspects could be a topic for future research.

The second level of model elements includes the activities that are measured in previous research on the impact of including a CCC in the logistical process related to construction. These aspects are marked with a light circle with a number in Figure 3 and are included in the model described in chapter 5. These aspects are the Consolidation into work packages at the CCC, the unloading activities on-site, the transportation on-site and the fixing process. The steps in the model could be practically tested with the data generated in previous research and available documents provided by the CCC Utrecht. All these elements could be part of the model when the required input data becomes available. Generating more experience data for these aspects by measuring the duration of the activities could improve the capacity of the model to predict in the impact of implementing a CCC on the costs of a construction project in more detail.

The last level of model elements includes the activities that are described in the literature and could be tested practically and in the Wonderwoods case. These aspects are marked with a dark circle with a number in Figure 3. These activities include transportation, waiting time, loading time, handling at the CCC, and storage at the CCC. In the Wonderwoods case, the factors are calculated with sector averages and for multiple scenarios. When the specific project data becomes available in more detail the model can be used to predict the impact of including a CCC on the logistical costs of the construction project to a higher degree of certainty.

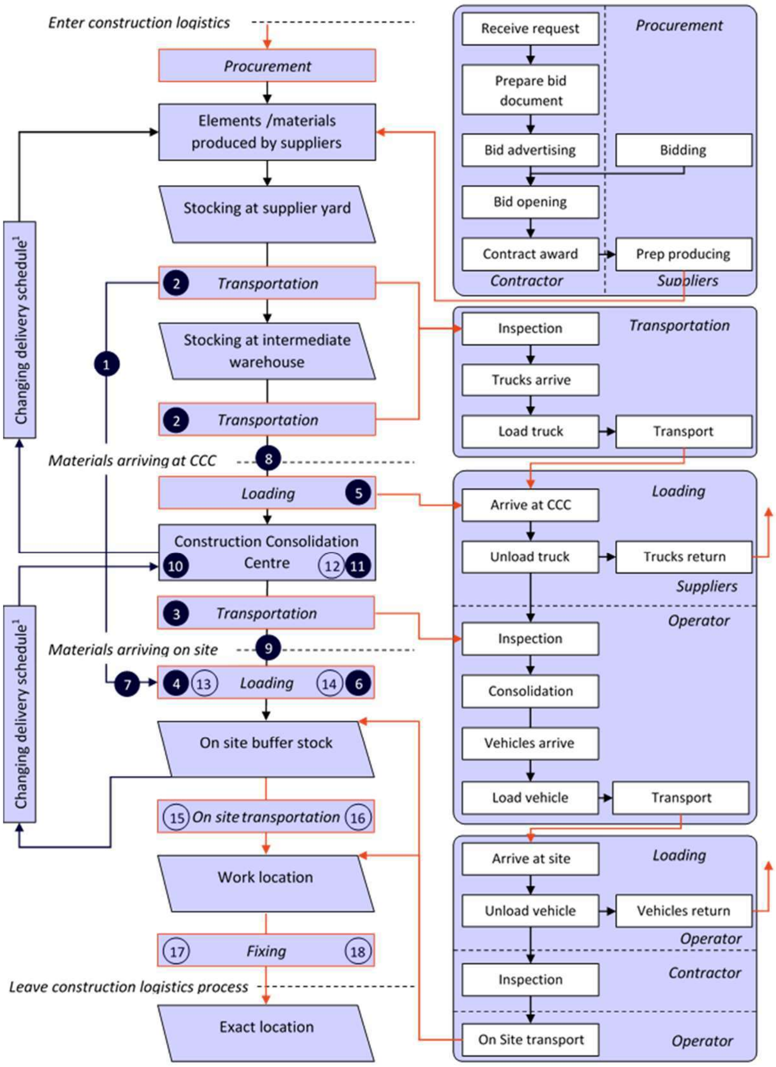

Figure 3 Framework III.

6. VALIDATION

To validate the process in which the calculation model is developed an analysis of all decisions is made. A technical overview of all decisions and input on which decisions are made is included in appendix M. The calculation model is the result of a continuous process including multiple iterations. The initial model is developed with the knowledge described in the literature. This initial model is further developed with employees of the operator of CCC Utrecht and multiple documents provided by the operator. The input of the experts resulted in a more pragmatical approach to modelling and a new calculation model. The new model is extended with the factors measured in previous projects of the CCC Utrecht that where measured and described in various reports of students and TNO. This complete and functioning model was tested in an action research setting in the Wonderwoods project which resulted in various decisions to enable insightful results for involved stakeholders. A number of modelling decisions are made during the development of the model.

1 *Reduction in stakeholders*

The initial model required (financial) information that is scattered across the entire supply chain of the construction project. Measuring all activities during the project or creating an ideal case as was done in the paper of Yuan Fang and Thomas Ng (2011) proved to be challenging in the process of developing the model. Knowledge of processes is scattered across stakeholders and can differ for each project and between the type of materials that are supplied and are therefore difficult to copy from a previous project. Information regarding the CCC itself is knowledge of the operator and is measured in previous research and is available for the development of a calculation model. The quality level of information is based on past projects and is limited due to the innovative character of the CCC in processes. Information regarding the project is in the possession of the main contractor. The project related data consists of the number of materials, technical specifications, the geometry of the building, and planning. The quality level of this information depends on the planning of the contractor and the activities that are conducted by the employees of the contractor in the preparation stage of a project.

2 *Reduction in costs factor complexity*

The initial model had a costs structure for all activities divided into costs for labour, equipment, material and capital. The first iterations of the model with information available in the past cases resulted in a new approach to the costs factors. The costs related to transport are reduced to a rental price per hour. The number of journeys can be influenced by the implementation of the CCC. The rental price, however, will stay the same and could, therefore, be calculated with the fixed price. The costs structure related to storage at the CCC was split by the operator of the CCC in handling costs and storage costs. Handling costs include the labour and equipment costs and have a fixed price the storage costs are calculated with a fixed rental price. Since the model is developed for implementation in practice the decision to adopt this approach in the model is acceptable.

3 *Limited to activities measured in previous research*

All activities included in the final model are factors that are measured in previous research. In the modelling process for the activities the outcome of the model could be compared and tested with the results of previous research to check the reliability of the model. The activities that are not measured in previous research are excluded from the model and are included in the recommendations for future research.

7. DISCUSSION

This paragraph provides an overview of the elements of this research that require discussion and the limitations within this research. The paragraph is divided over two topics being the developed model and the research scope and process.

Discussion and limitation of the model

The model developed in this research compares the difference between the traditional process and the new process including the CCC. Expected savings are based on data collected from different comparable projects and previous research. The input for these factors could, however, be discussed.

- **Savings on transport** - The savings on transport are an important factor for the profitability of including the CCC in the process. Based on average load factors in the construction industry measured in previous research it is assumed that suppliers in the traditional process deliver to the construction site with 40%. It could be possible that the suppliers for a specific project are able to optimize the transport to site and increase the load factor. The average distance is calculated for multiple distances including the sector average of 75km. The journeys are calculated with a single type of truck with a specific maximum capacity. When the level of detail in the information increases however and the process for a specific supplier becomes available. It could occur that all aspects are more optimistic and the savings by changing the process diminish. All these factors could potentially be influenced by the main contractor. If suppliers are sourced locally the transport distances become so low that savings can not cover the costs. Previous projects, however, showed that sourcing is project-specific and depends on the type of materials used and the available suppliers for these materials. The high influence of the process and the project-specific situation could be an argument for postponing the modelling process of the CCC until this level of detail in the process is reached.

- **Traffic** - The duration of the journeys in the model is calculated with an average speed on the highway and average speed in the inner city. In reality, trucks deal with increased traffic in peak hours. One of the advantages of the CCC is that suppliers are free to deliver in off-hours and are able to avoid peak hours. This could potentially lead to higher savings on transport costs than the developed model calculates. This factor is mentioned by one of the experts in the conducted expert survey. Including this factor could increase the exactness of the model output.

- **Storage costs at CCC** - The buffer storage costs at the CCC are calculated with a standardised period of two and three weeks. This factor can be influenced by the project and the approach to the construction process. If the day production of the project is so high that the material deliveries to the CCC with full freights and the deliveries of the CCC with full freights to the construction site are only a few days apart from the storage capacity and time needed at the CCC will be lower.

- **Costs related to storage** - Buffer storage and handling at the CCC in this research are calculated with the cost estimations of CCC Utrecht. In the current model, this storage is added as a costs factor to the process. However, the storage capacity of the CCC could potentially lead to a decrease in capacity needed at the supplier's yard or intermediate warehousing. This could generate potential extra savings for the suppliers of the materials.

- **Benchmarking** - The developed model compares the traditional approach to construction logistics with the process including the CCC. This is a snapshot of the project at a certain moment in time. Changes to the type of materials or the process during the execution of the project could diminish the effects calculated in the preparation stage of the project. This needs to be considered when changes are made during the execution of the project.

Discussion and limitations of the research

The distribution of construction logistics costs is based on the contractual agreements amongst the owner, main contractor and suppliers. However, the total costs of the project will be transferred to the owner who needs to pay for the project in the end. Therefore this study adopted the perspective of Yuan Fang and Thomas Ng (2011) to consider the construction logistics costs from the owner's viewpoint. During the research, the perspective on this matter changed. In the process including the CCC, the main contractor is the client of the CCC and therefor the stakeholder to convince of the savings in the process.

The model developed in this research is for the projects that are tendered based on Design-bid-built. This is currently the most used contract in the Dutch construction sector and is a process with a finished design before contractors are selected. A finished design limits the variables in the initial model for comparing the construction logistics costs when implementing or not implementing a CCC. Insight from this study could potentially lead to design input in new projects, due to time limitations this process is excluded from the scope of this research.

The conducted literature research resulted in an extensive list of activities and cost factors included in the construction logistics process. A number of activities could not be tested with results from previous research and are therefore excluded from the model despite the fact that they could potentially be impacted. These factors are therefore included in the recommendations for future research. Other activities could be tested with the results from previous research but due to missing project related information could not be tested in the conducted case study. In the survey amongst expert is mentioned by multiple experts that these factors should be included in the model and that the data should be made available in the project.

A barrier for the implementation of CCCs in construction projects as discussed in the introduction is the lack of financial models that measure the impact on efficiency and costs for the involved parties. Therefore, this research is focussed on the development of a financial model from a business economics perspective. Actual costs (savings) that are part of the construction process are included in the model. The transparency of these costs could convince private parties to implement the innovations in their processes. The implementation of these innovations could, however, have financial benefits for society as a consequence off ecological benefits, reductions of traffic in inner cities etc. Transparency of these costs (savings) could lead to the involvement of public parties. These public costs (savings) are not included in the developed model because they do not influence the current supply chain.

8. CONCLUSIONS

By effectively carrying out the research and answering the sub-questions of the research the main research question can be answered. The answers to the sub-questions are included in chapter 9 of this research.

> To what extent can the logistical costs related to construction be modelled in the preparation stage of a project to predict the impact of the implementation of a Construction Consolidation Centre?

The logistical costs related to construction are defined in this research as the costs related to transporting (travelling, waiting, loading), cost at the CCC (handling, storage, and consolidation into work packages), and cost at the construction site (unloading, transport and fixing).

All the cost factors are included in the model developed in this research and are tested with either past case data, or with past case data and the data in the case study. The model can be used to calculate the logistical costs related to construction to predict the impact of the implementation of a CCC on the project to a large extent. The calculations, however, require experience-based data for the activities of the CCC, generic cost data for aspects like rental prices and labour costs, and project-related input data. The extent to which the model can predict the logistical costs related to construction depends on the level of detail of the provided data. This data should be available at a certain moment in the preparation stage of the construction project.

Implementing the model in an earlier stage of the project is still possible when the selection process of suppliers has not yet started, and project-related input data is only available on a general level. In this situation, the model can be used to provide some insights about the potential impact of the implementation of a CCC. This approach is based on sector averages for transport distances, average load factors, standardised modes of transport and rough estimations of the material quantities and time consumed in activities. With these estimations' insight into the savings on transport, waiting, loading and the costs at the CCC can be provided to the main contractor for multiple scenarios.

9. RECOMMENDATIONS

Recommendations for future research

The recommendations for future research as a result of the conducted research contain the following aspects:

- **Missing activities** - In this research a couple of activities included in the initial model could not be tested with results from previous research. These activities are the procurement, process management, stocking at the supplier's yard, and stocking at intermediate warehouses. Measuring the impact of a CCC on these aspects could be a topic for futures research.

- **Increasing the database** - The aspects included in the model are tested with results of previous research on the impact a CCC has on activities in the logistical process. Data on activities related to consolidation, and activities on-site lacked generalizability. Increasing the experience-based data on the processes including a CCC will enable the further development of models and will contribute to proving the impact of innovations in construction logistics.

- **Missing cost categories** - In this research, the costs category of capital, including opportunity cost frozen in inventory as explained in literature is not included in the developed and tested model. Analysing the process and tracing back these costs to the cost owner could highlight another aspect that is impacted by the implementation of the CCC. A faster construction process could potentially lower these costs.

- **Factors for implementation** - In this research, the factors that can impact the implementation of the model could only be tested by observations in limited time for only one project. Analysing the project organisation and its members and their influence on the implementation could help with a better understanding of the factors that influence the implementation of both the model and the CCC. Conducting this type of research could also help with a better understanding of the output that should be generated by the model to convince the involved project members.

- **Smart solutions for personnel** - This research is focussed on the activities included in the delivery of materials to the construction site. The CCC also enables an alternative for the process by which the construction workers get to the construction site. In future research, the possibilities of including these activities and alternatives like a shuttle service in the model could be tested.

- **Combining supply with the waste collection** - The scope of this research is predicting the impact a CCC could have on the supply of materials to the construction site. Measuring the impact, a CCC can have on the process of waste collecting from sites could be a topic for new research.

- **Monitoring the Wonderwoods project** - A final recommendation would be to monitor the Wonderwoods project during the construction. Measuring the actual transports distances, waiting times, loading times, load factors, consolidation times and costs and on-site transportation could be beneficial for benchmarking the predictions made with the current model and could help to improve the current model to one that can be used in other projects as well.

Recommendations for practice

The recommendations for practices as a result of the conducted research are:

- **Communication structures** - Focus on the communication structure of information from the contractors and suppliers to the operator of a CCC and vice versa. This will reduce the time consumed in the modelling activities.

- **Transparency** - Implementing innovations like the Construction Consolidation Centre requires collaboration and transparency within the supply chain. Costs savings as shown in this research are theoretical and will only lead to actual savings and increased implementation of CCCs if implemented and discussed during the contracting stages.

- **Investing in input data** - Calculating the benefits of the innovations in the research required a benchmark with the traditional process. Investing in infrastructure to enable continues measuring of the construction process to collect this data can help to prove the profitability of innovations.

- **Generic cost data** - Building a large database of generic cost data of construction processes for benchmarking requires a lot of resources. Collaboration with companies that are specialised in collecting and managing these databases could be beneficial for the development of costing models in practice.

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INTRODUCTION

Part I

1. CONSOLIDATION

Over the past years, construction activities in the Netherlands shifted from spacious greenfield developments to dense inner-city redevelopment projects. Approximately 50 per cent of the total turnover in construction is generated within the country's large cities. It's expected that this percentage will grow to 80 per cent in the near future(De Bes et al., 2018). Inner-city construction activities and the large logistical supply stream connected to it has a large impact on the liveability of the city. Almost 30 per cent of al business traffic is related to construction logistics (Vrijhoef, 2018). Consequences of these activities are a nuisance for neighbours due to noise, congestion, poor air quality due to the emission of greenhouse gasses and particulate matter, and a negative impact on road safety (De Bes et al., 2018) (Vrijhoef, 2018).

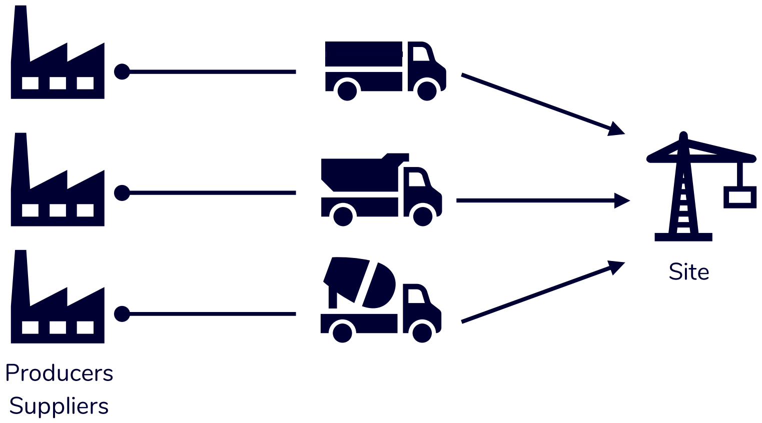


Figure 4 Traditional Construction Logistics

The development of Urban Consolidation Centres (UCCs) and Construction Consolidation Centres (CCCs) helped to improve the efficiency of freight transport in cities and thereby to reduce the impact on the traffic, the air quality and nuisance for residents. These centres are a step in the logistical process between suppliers and stores (UCCs) or construction sites (CCCs). Instead of multiple deliveries from al suppliers directly to the sites as can be seen in Figure 4, the freight will be sent towards the Consolidation Centres located in the periphery of the cities as can be seen in Figure 5. CCCs offer a wide variety of services examples are the consolidation of loads from multiple suppliers into one truck, consolidation in one-day work packages in combination with just-in-time delivery to sites, stockholding and express delivery etc. It is site-dependent what services are included in the process.

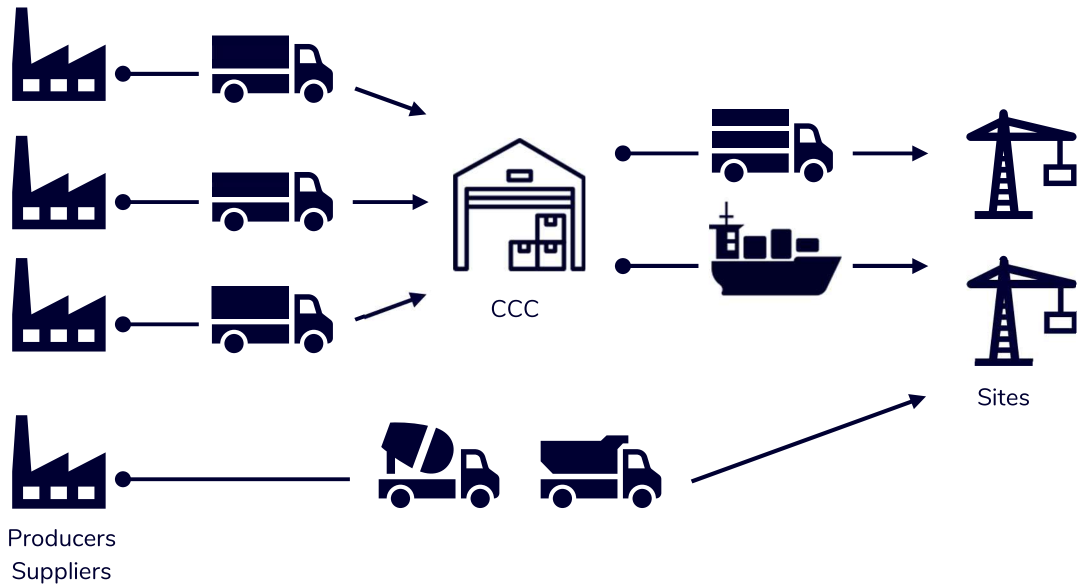


Figure 5 Construction Logistics with CCC

2. SOCIAL RELEVANCE

Construction logistics in urban areas can be a source of hinder and nuisance for the people in the city as mentioned in the previous paragraph. Traffic jams, produced noise, and pollution of the air by the emission of carbon dioxide and Particulate matter are examples of the problems caused by construction and logistical processes. Case examples in which innovative logistical solutions like a Construction Consolidation Centre were included in the project, showed reductions of nearly 70 per cent in logistical movement around construction sites (De Bes et al., 2018) (Transport for London, 2008). Improved vehicle load consolidation and the opportunity to use for example electric or other alternatively fuelled goods vehicles instead of diesel for the deliveries from the CCC to sites, due to the relatively short distance. The use of these cleaner vehicles results in reduced emissions of $CO2$, Nitrogen Oxides, CO and Particulate Matter(PM) (Allen, Browne, Woodburn, & Leonardi, 2014). This drastically reduced the caused hinder and nuisance and therefore improved the life of the people in the city.

Apart from the reduction in nuisance, the implementation of the Construction Consolidation Centre also proved to reduce the number of construction materials damaged, lost, stolen and over-ordered compared with typical construction projects (Transport for London, 2008) (Sullivan, Barthorpe, & Robbins, 2010). Reducing the materials used for construction will reduce the impact on the earth’s limited resources. Lack of production capacity at suppliers of construction materials is one of the barriers in dealing with the demand for construction activity(ING Economisch Bureau, 2018). A reduction in material orders as a result of using the CCC could help to (partly) solve these problems. Proving a significant reduction in construction waste was difficult due to measuring problems (Transport for London, 2008). Dealing with the produced waste in the CCC, however, led to creative solutions to reduce waste and stimulate repair and reuse of pallets for example. Again, lowering the impact on the earth's resources and benefiting society.

The CCC can add a wide range of value-adding logistical service activities. These activities can lead to increased supply chain efficiency, responsiveness and business performance as well as cost reductions. A few examples are reductions in delivery lead times, reliability of product delivery, and reductions in stock losses (Browne, Woodburn, & Allen, 2007). The innovative logistical solutions also had a positive impact on labour productivity on site. Reductions of 20 to 25 per cent are proved in several projects(De Bes et al., 2018). Together these results could lead to increase construction capacity, which will be beneficial in solving some of the challenges the sector is facing. Two examples of these challenges are;

The energy transition. As a result of the 2015 Paris Agreement, the Dutch government included a reduction of 55% greenhouse gas emission by 2030 and a 95% reduction by 2050 in comparison to 1990 in a new Climate Bill (Tweede Kamer, 2016). As a result of the transition, the construction sector will need to produce higher-quality buildings which will use significantly less energy. By the year 2020, all new-build buildings need to be Almost Energy Neutral (BENG). The guidelines for BENG include a maximum energy need of the buildings, maximum use of fossil fuels and a minimum share of renewable energy (Rijksdienst voor ondernemend Nederland, 2018). The transition will also stress the need for an upgrade of the existing building stock.

The demand for newly built dwellings. Besides the challenge of increased quality and the challenge of upgrading the current housing stock, there is a large demand for newly built dwellings. Growing numbers in households, demand by elderly people and starters as well as a shortage of approximately 175.000 dwellings in the rental sector are part of this demand (AD, 2019). In the spring of 2018, the Dutch government stressed the need for a million new homes by 2030 (NU.nl, 2018).

Developing the proposed costing model and framework for implementation contributes to an increased chance of implementation of innovative logistical solutions like the Construction Consolidation Centre. This research is for these reasons beneficial to society.

3. SCIENTIFIC RELEVANCE

This research is based on a gap in the literature. Previous research has indicated the benefits of implementing Construction Consolidation Centres in construction projects within the Dutch construction sector. Research on the impact of implementing the CCC on the financial performance of a construction project has not yet resulted in financial models for cost accounting. The relevance of these models is mentioned in the work of TNO.

In their research, TNO analysed nine construction projects and concluded that; successful experiments in sustainable construction logistics not yet led to the implementation of the new methods in the inner-city construction sector. Multiple large contractors are aware of the necessary change in mindset and the need of new financial models that can show the effect of innovative solutions and the new division of revenue within the supply chain (De Bes et al., 2018). Construction logistics needs to be implemented during the design and procurement phase of the construction project to create an effective plan. The purchasing department of the contractor can play an important role in this process. A change from purchasing on project bases to purchasing on added value for the supply chain is necessary (De Bes et al., 2018).

Financial modelling for construction projects including a CCC has not yet resulted in new models. Models for analysing the construction logistics process, however, have been researched in the past. If the construction industry endeavours to improve the efficiency and effectiveness of their operations, it is necessary to fully understand the behaviour of their processes (Back, Maxwell, & Isidore, 2000). Modelling of real-world processes will often require a description of all involved activities with stochastic durations, each linked together in a precedence logic. If resources, such as labour, material, and equipment, are required to perform the activities, an activity-based costing(ABC) technique must be developed that can accurately accommodate the inherent variability of the process to accurately predict the costs (Back et al., 2000). The aim of an ABC system is to provide complete traceability of actual costs within a process for better costs management. Applying these types of quantitative analysis to the construction logistics process will allow construction companies to understand, prior to investment and implementation, how the selected processes will respond to change. Yuan Fang and Thomas Ng (2011) applied the ABC method to a case example for a precast concrete wall supplier. They concluded that the ABC method could be beneficial for tracing consumed resources back to the consuming activity and subsequently to a particular cost element. The model could also help construction managers and planners with the optimization of the construction and material delivery schedule. This would result in the most costs-effective solution, which could, in turn, help them to establish a competitive tender price for a project. The authors, however, do stress the need for further development of the model. Validation with experts from contractors and suppliers in a real project is necessary to test the applicability of the model in other projects and with other materials (Yuan Fang & Thomas Ng, 2011).

This research contributes to the body of scientific knowledge with the development of a new costing model to predict the costs benefits of including CCCs in a construction project. The knowledge of the activities included in the project and activities influenced by implementing the CCC increases and the model will be validated with experts in a real project with different materials for the finishing stages of the project instead of the structural elements as described in previous research.

4. READERS GUIDE

This report contains six parts. The content of all parts is explained briefly.

Research introduction I

The first part of the research introduces the development of Construction Consolidation Centres and their benefits. The social and scientific relevance of the research is explained thereafter.

Research design II

This part of the research is focussed on the design and methodology of the research. It contains the conceptual model, research scope, the aim and objectives, the research questions and the methods that are used.

Theoretical background III

The theoretical background of this research consists of two chapters. The first chapter elaborates on the history, typologies, activities, and benefits of Construction Consolidation Centres. In the second chapter, the cost accounting models described in the literature are explained. The type of costs included in the models are described and a new activity-based costing framework for cost accounting is developed.

Empirical research IV

This part of the research describes the development of the model with input from previous research on projects in the Dutch construction sector. The developed model is tested in the Wonderwoods project and the final model is validated with experts from practice.

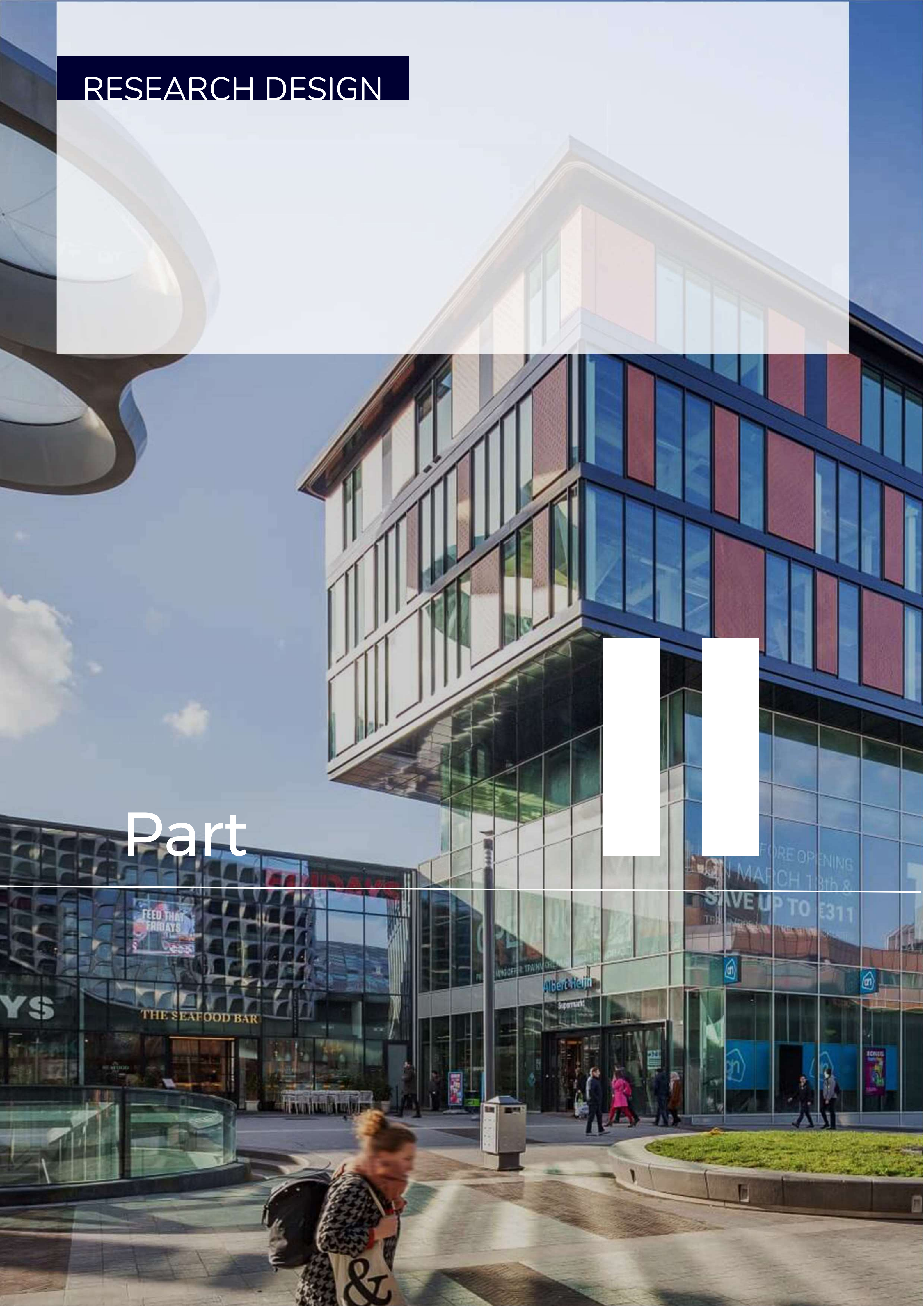
Results V

The final part of the research consists of a discussion and limitations of the research results, an answer to the research questions, recommendations for practice and future research and a reflection on the research.

Addendum VI

RESEARCH DESIGN

Part II



The conceptual model of this research can be seen in Figure 6. This research explores to what extent logistical costs related to construction can be modelled in the preparation stage of a construction project to predict the impact of the implementation of a Construction Consolidation Centre on the total costs of a construction project.

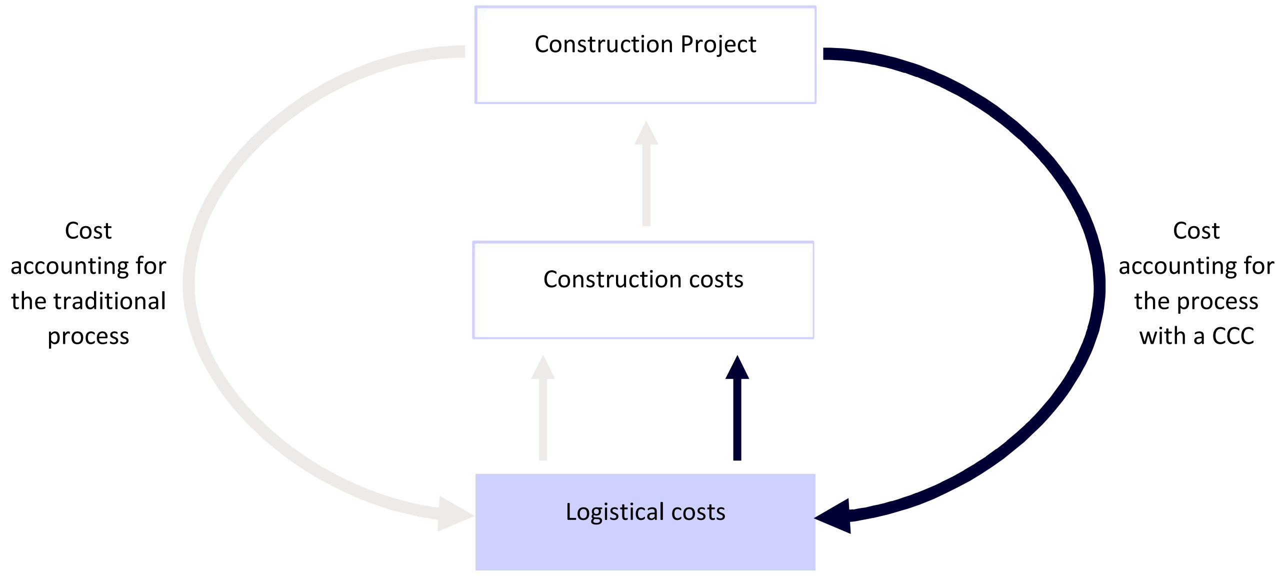


Figure 6 Conceptual model

The research is focussed on modelling the logistical costs related to construction in the preparation stage of the construction project. The results of the modelling process can be implemented during the execution of the project in the construction stage of the project. The consolidation activities mainly take place during the finishing stages of the project. In this stage of the project, the number of different materials and suppliers is high and the size of materials relatively small which enables consolidation. The research scope can be seen in Figure 7.

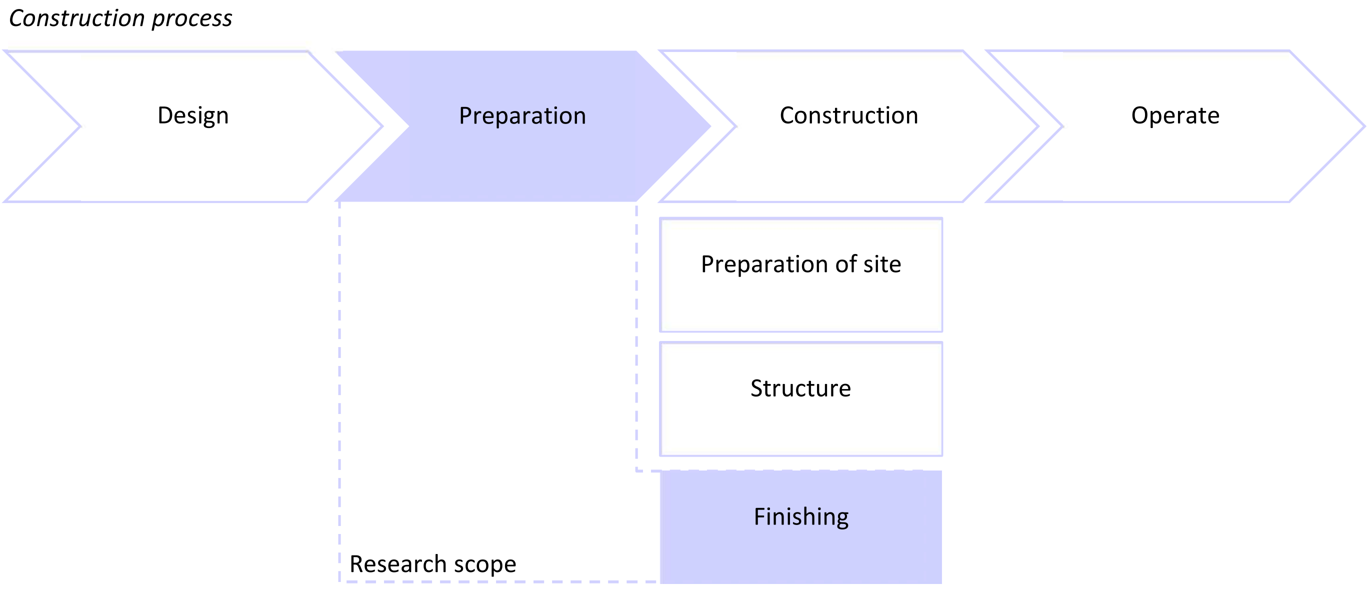


Figure 7 Research scope in construction process

The benefits for society and involved companies would suggest that the CCCs are a great success and are widely used in practice, the reality is different. Researchers debate the ability of CCCs to be financially self-sufficient (Browne et al., 2007) or state that the implementation of CCCs in the construction process is expected to increase when the financial benefits are transparent. De Bes et al. (2018) stress the need for the development of financial models that enable supply chain partners to consciously decide for the implementation of Construction Consolidation Centres based on predicted financial benefits. An important step in the development of these new logistics solutions is proving their value by measuring the impact on efficiency and costs (De Bes et al., 2018). These statements in literature formed the base for this research and led to the following problem statement.

Problem statement

The implementation of Construction Consolidation Centres in the Dutch construction sector is limited due to a lack of tools to prove the financial benefits. A calculation model that predicts the impact of the logistical costs on the construction costs in the preparation stage of the project to prove the financial benefits of the Construction Consolidation Centres has not been developed yet.

Aim

The aim of this research is to develop an alternative model for cost accounting in the construction industry. This model includes the activities of the construction logistics process impacted by the implementation of a Construction Consolidation Centre. The developed model needs to enable the prediction of the impact of the implementation of a CCC on the costs of a construction project in the preparation stage of the process.

Research objective

The first objective of the research is to provide insight into the effect of the Construction Consolidation Centre on the total costs of a construction project with a costing model. This part is focussed on providing a framework that describes what data is needed from involved parties to calculate the costs in the preparation stage of the project. How these costs can be modelled and how the output of the model can be useful in the decision-making process.

The second objective of the research is to provide insight into the conditional factors for the implementation of the model in the project organisation by the companies that are part of the supply chain. Increasing awareness and adjusting the proposed model to these factors could increase the chances of implementation in practice.

3. RESEARCH QUESTIONS

The conducted literature review and formulated problem statement resulted in the following research question. To further structure the research question is divided into multiple sub-questions.

Research question

To what extent can the logistical costs related to construction be modelled in the preparation stage of a project to predict the impact of the implementation of a Construction Consolidation Centre?

Research sub-questions

1. Which definitions and aspects of construction logistics need to be included in the model?
2. Which information should be available in the preparation stage of the project to provide input for the model and which generic cost data can be used?
3. How to accurately model and predict the financial impact of using a Construction Consolidation Centre in a new costing model?
4. What Output should be generated by the model to create added value in the preparation stage of the project?
5. Which conditional factors determine the implementation of the model?

1. *Which definitions and aspects of construction logistics need to be included in the model?*

Answering this question will provide the basis for the development of a new model, either by adopting one from literature or combining multiple existing models to an entirely new model. To answer this question, a literature study of available costing models for construction logistical projects and the elements of these models is conducted.

The result is a conceptual framework for the development of a new model and a list of the costs factors that will be included in the new model.

2. *Which information should be available in the preparation stage of the project to provide input for the model and which generic cost data can be used?*

The objective of this question is to understand the costs predicting process in practice. This knowledge will help with aligning factors named in literature with the characteristics and availability of information in practice. To answer this question, an analysis of the information that should be available in the preparation stage of the project to provide input for theses model will be conducted. A document review of traditional models and input for these models and interviews with multiple experts will be used to answer this question.

The results form a base for the input guidelines for the new model.

3. *How to accurately model and predict the financial impact of using a Construction Consolidation Centre in a new costing model?*

Answering this question will result in a new costing model that can be tested in a case study of a past project. The model will be tested with the “traditional process” of the selected sub-contractor. Verification that the model will generate the same outcome as the traditional process if the input conditions stay the same and first insights of the model if conditions change to a situation in which the Construction Consolidation Centre is included in the process.

The result of answering this question is a tested and functioning concept of the new costing model.

4. *What Output should be generated by the model to create added value in the preparation stage of the project?*

Answering this question generates insight into the necessary output of the developed costing model. To answer this question the model will be tested in a current case with a scenario that a Construction Consolidation Centre will be included in the project. The output of the model for this scenario will be discussed with experts and the added value of the model output will be verified.

The result of answering this question is a functioning costing model that generates useful output for the involved stakeholders.

5. *Which conditional factors determine the implementation of the model?.*

The final step in the process is qualitative research into the conditional factors that determine the implementation of the new costing model within the organisation of the construction project. Answering this question will increase the change of implementation of the costing model in future projects of involved companies and other interested market parties. To provide an answer to this question a review of literature on the topic and interviews with experts involved in the case study project is conducted.

The result of answering this question is a list of conditional factors that need to be met for the successful implementation of the new activity-based costing model.

Data analysis summary

Table 1 provides an overview of the research steps for each subquestion with a recap of the proposed methods, data collection, data source and data analysis.

Subquestion	**1**	**2**	**3**	**4**	**5**
Methods and techniques	-	Case Study	Case Study	Case Study	Case Study
Data collection	Literature review	Document review Interviews	Document review Interviews	Document review Interviews Expert panel	Literature review Document review Interviews
Data source	Search engines	Past case to test/verify the model	Past case to test/verify the model	Current case to apply the adjusted model	Search engines Experts
Data analysis	Selection of definitions and aspects	Selection of necessary input for the model	Selection of necessary input for the model	Selection of useful output of the model	Selection of the conditional factors for the implementation of the model

Table 1. Research structure overview

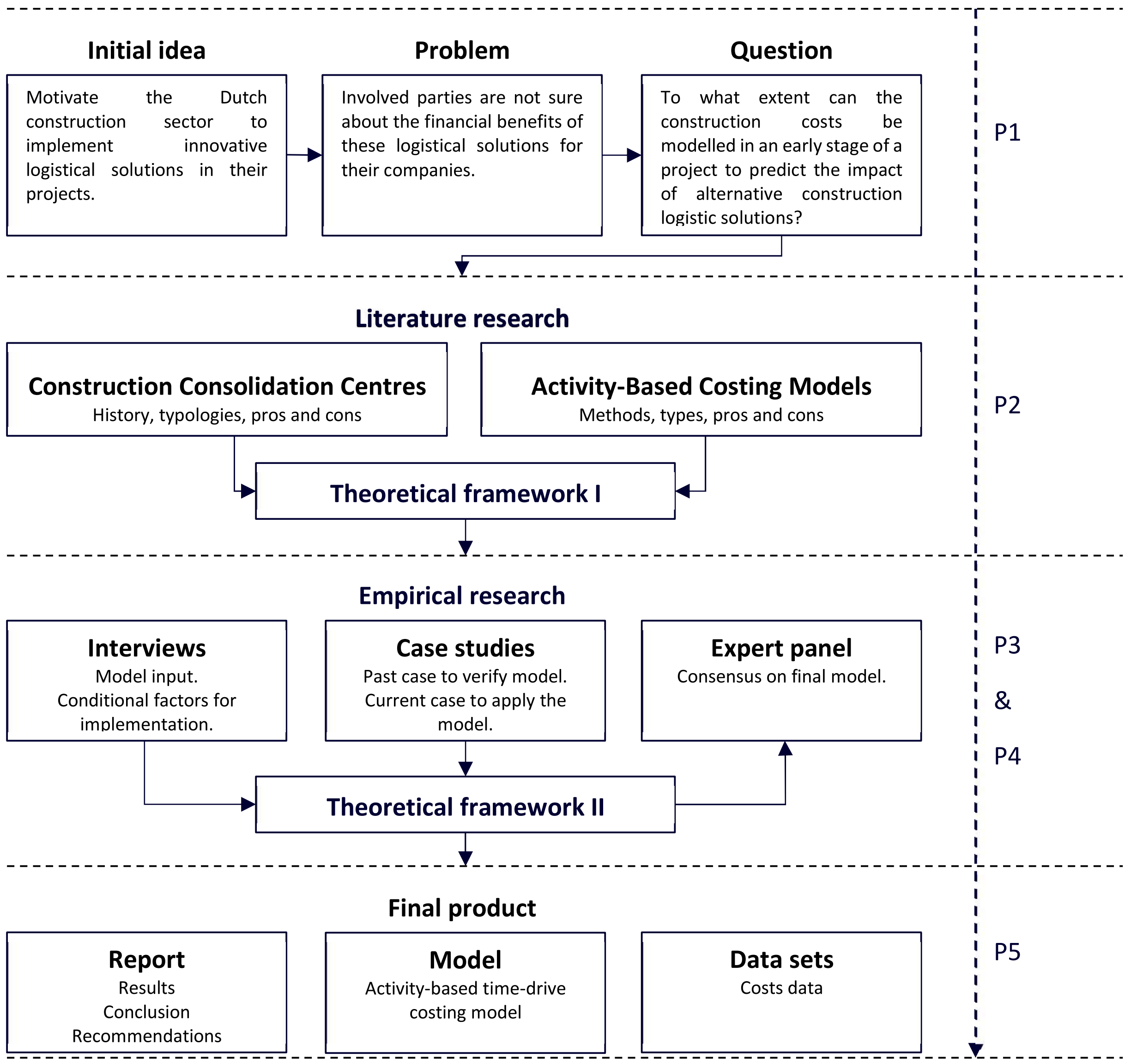


Figure 8 Research structure overview

Data plan

The data collected for this research is partly transparent and partly confidential due to the competitive advantages of the companies involved in the process. The final report of this research will be findable through the repository of the Tu Delft and will be provided by the author if requested. The input data for the model will be partly opensource, drawn from standard costs estimates and therefore accessible for interested parties and partly provided by the companies involved and therefore confidential and only provided if requested for research purposes. The interoperability of case study data is guaranteed due to standardised methods for analysing and structured method for reporting. The reusability of data depends on the outcome of this research. It is expected that the newly developed model will show the financial benefits of new logistical solutions and the framework for implementation will be complete. Therefore, the model and implementation framework could be reused for new case studies and could be helpful in testing other process optimization strategies in construction logistics.

Ethical considerations

In this research, a process optimization with increased construction efficiency and costs savings are proposed. Both are a good thing in principle, however, could have a negative impact on some of the stakeholders involved in the process. Take for example the construction worker interviewed in by Russcher (2016) in his research for costs optimization by construction logistics. Taking away all side jobs connected to logistics, made the construction worker feel like a robot only fit for one task. Aspects like this need to be taken in to account when implementing the proposed changes in the process.

The second ethical consideration is a result of the costs optimizations. The model will be developed from the perspective of the client; however, costs and revenues will still be made by different stakeholders as agreed in the contract negotiations. In the ideal world, the costs savings will be redistributed equally amongst all involved stakeholders and the costs savings will not result in losses for some involved stakeholders. In practice, however, redistribution could be influenced by the negotiation power of the involved stakeholders.

Dissemination and audiences

The audience of this research consists of all employees of the contractors in the Dutch construction sector involved in the costs process of construction, the employees of construction logistics companies, the employees of sub-contractors and the employees of material suppliers. The delivered model could provide new insights for their way of working and will be shared with all stakeholders involved in the research process.

THEORETICAL BACKGROUND

Part III

In this paragraph, a brief overview of the history of the development of international construction consolidation centres is presented. This overview is by no means exhaustive and serves the purpose of introducing the characteristics of these centres. Research into Consolidation Centres as a means by which to reduce the impacts of urban freight transport initiative started in the early 1970s and has gained increasing levels of interest during the last decade (see for example (Browne et al., 2007); Transport for London (2008); Sustainable Urban Consolidation CentrES for conStruction (2017); De Bes et al. (2018)).

Potsdamer Platz Consolidation Centre

During the '90 the reconstruction of the Potsdamer Platz area in Berlin was one of the largest construction sites in Europe. A construction consolidation centre was implemented with the aim to minimize logistics problems related to constructions works in the city of Berlin. After an agreement between the private companies and the public bodies was reached the CCC was established in August 1993 and operated till 2002 (Sustainable Urban Consolidation CentrES for conStruction, 2017).The services provided by this CCC consisted of Removal of all excavated material, concrete manufacture and delivery, deliveries management and waste management.

Old London Construction Consolidation Centre

In 2005 a two-year trial CCC project was started in London during the construction of major new office blocks (4 sites in total). The CCC was located in South Bermondsey, approximately five kilometres south of the City of London (Transport for London, 2008). The aim of the CCC was to create a reduction in freight journeys, a reduction in a journey time of supplier deliveries to contractors and high delivery reliability. (Allen et al., 2014)

The services provided by the CCC consisted of consolidation of goods and delivery to site. The CCC managed to reduce the journey time of suppliers to construction sites by 120 minutes, operated with delivery reliability of 97% and reduced freight journeys to 60-70%. The OLCCC project costs £3.2 million of which Transport for London funded £1.85 million, and Stanhope and Bovis Lend Lease: £1.35 million (Transport for London, 2008).

New London Construction Consolidation Centre

In 2008 the New London Construction Consolidation Centre was opened and is still open nowadays. The consolidation centre is with a storage capacity of 15,000m2 three times the size of the old CCC. The CCC is privately operated by Wilson James with approximately 52 employees. Contractors can voluntarily use the services of the CCC and are not obliged. The main purpose of the CCC is to promote the efficient flow of construction materials through the supply chain to the actual points of use on the project. They do this by offering free storage for the first 30 days, security is present therefor materials are safer than on construction site, they conduct quality control, they act as a waste operator, and they provide a packaging process(Sustainable Urban Consolidation CentrES for conStruction, 2017) (Sullivan et al., 2010).

The New London Construction Consolidation Centre has booked impressive results in past years;

- Reduction in a number of construction vehicles entering the Cite of London by 68%.
- Certainty in supply is improved to (100% availability in 24 hours).
- Increase in on-site productivity as a result of less labour downtime of 47% (no more searching for material).
- Reduction of waste by 15% as a result of less damage.
- 25% reduction in an on-site accident as a result of safer work environments.
- The delivery performance of 95% of goods delivered right material-right place-right time
- Reduction in a supply journey time of approximately 2 hours (40 minutes to enter the city and 40 minutes to leave).
- Reduction of Co2 emissions run-up at 80%.
- Reduction of unloading time to 40 min instead of hours.
- Reduction in the over-ordering of materials of 14%, as a result of better management of materials on site.
- Greater delivery flexibility since suppliers can send full loads and contractors are allowed to order smaller batches.

This paragraph is focussed on the different types and characteristics of Consolidation Centres. According to (Browne et al., 2007) Urban Consolidation Centres and Construction Consolidation Centres can be classified into three main types. Each type of UCC can offer either relatively basic consolidation services or a much wider range of value-adding logistics activities such as stockholding, goods return and waste collection services.

Special project UCCs

These types of UCCs are used for non-retail purposes. They can serve a single construction site but hold the potential to serve on the geographical scale of the urban area. It's not uncommon for this type of UCCs to exist for a given period of time while the construction activity linked to the UCC takes place.

UCCs on single sites with one landlord

These UCCs are built as a single development so it could potentially be included in the planning of the site. The landlord has the potential to insist that tenants use the UCC. Unloading points are off-street in a specially designed delivery area. The operation of this type of UCC can potentially be made self-financing through rent structures and handling charges. This type of UCC is most applicable to the retail sector and therefore not reviewed in this research.

UCCs serving a town/city

These UCC types vary in terms of the geographical area they serve, ranging from a small district such as a historic centre or a larger more diverse geographical area up to an entire town. They also vary in terms of the number of companies operating the UCC scheme, which could be a single company or several companies.

	Potsdamer Platz CC	**Hammarby CC**	**Old London CCC**	**The nine Elms CCC London**	**New London CCC**
Country	Germany	Sweden	UK	UK	UK
Type	Special project CCC	Special project CCC	UCCs serving a town/city	Special project CCC	UCCs serving a town/city
Users	Multi	Multi	Multi	Single	Multi
Site	Multi	Multi	Multi	Single	Multi
Operation period	1992-2002	2001-2004	2005-2007	2007-2010	2008- still in operation
Operator	-	Subcontractor	Wilson James	Mlogic	Wilson James
Scheme	Mandatory	Compulsory	Test	Mandatory	Voluntary
Exceptions	-	Special materials like concrete	-	-	Steelworks and concrete

Table 2. Overview of CCCs with different typologies.

3. CCC ACTIVITIES

The primary function of Construction Consolidation Centres in the periphery of a city is the consolidation of goods and delivery to construction sites. In practice, the CCCs offer a wide variety of services. Characteristics of the project, construction sites and host cities influence the decisions for implementation of these services in a project. An overview of the services described in the work of Transport for London (2008); De Bes et al. (2018); Sustainable Urban Consolidation CentrES for conStruction (2017)) is listed below.

Logistics coordination - Coordination of the deliveries to construction sites is organised by employees of the CCC. Transport is adjusted to the local traffic situation. The arrival of materials is known to the main contractor in advance and can be ordered in one place.

Just-in-time delivery - The relatively short distance from CCC to the construction sites increases the reliability of transport arrival in specific time slots. This is required in inner-city construction projects with relatively little space for on-site storage.

Buffer storage - The CCCs have a short stay storage space for materials. This buffer enables the CCCs to decrease the number of inner-city freight transports by combining different material supplies into trucks and supply just-in-time. It enables suppliers to deliver full freights of materials at the CCCs instead of smaller freights directly to construction sites.

Day production packages - Materials for one day of production will be consolidated and transported from the CCCs to the site. These services can be provided after standard working hours on-site to minimize disruption of the construction processes.

Prefabrication - Besides consolidation in day production packages the CCCs offer the possibility to prepare materials for fixing. Certain processes for example kitting can be transferred from the site to the CCCs.

Warehousing - CCCs can provide warehousing services for suppliers that lack the space to store elements in or close by their factory. Projects that have elements with a long production process and short assembly process could require this storage capacity.

Site logistics - Transport on-site can be combined with transport to sites. The CCCs can provide teams with runners that place the materials next to the place where they will be fixed by the construction workers.

Waste transport - Transport of materials to the site and on-site can be combined with waste transport. Instead of collecting and sorting waste on the construction site it can be collected by the runners and be transported back with the trucks that brought the materials to the site.

Shuttle service - The CCCs can offer parking lots for the construction workers and offer a shuttle service to the site to compensate for a lack of parking lots on small sites and to prevent extra traffic by all the vehicles in the city.

Express transport - Extra or missing materials can be delivered from stock by small trucks from the CCCs with minimal delay for the construction process.

4. BENEFITS OF CCC

The benefits of the Construction Consolidation Centres depend on the usage of activities provided by the CCC and the type of CCC. The construction site that uses the CCC and the design of the buildings also greatly impact the effectiveness of these logistical innovations. Benefits of using CCCs will not occur in every project, however, based on the literature described in this chapter a list of possible benefits of the CCC is listed below.

Transport

- Reduced vehicle movements and distance travelled by improving load factors and reducing empty running
- Increased reliability of the deliveries (on time and right place, and in line with agreements)
- More flexibility and punctuality of the deliveries
- Efficient use of vertical transport materials on site (due to using in of-hours)
- Reduced waiting times before unloading on-site
- Reduced unloading times on site
- Opportunity to use clean vehicles on roads or transport on water
- Opportunity to combine waste transport with deliveries

Service by CCC

- Materials are stored in a secured location.
- Insight into stock for deliveries to site
- One contact for delivery of materials to the site
- Flexible response to express orders
- Opportunity to prefabricate

On-site

- Less storage capacity required on the construction site
- Reduced handling of materials on-site results in less damage to materials
- Increase in on-site productivity as a result of less labour downtime
- Reduction in accidents as a result of cleaner and safer work environments

Environmental

- Reduction in number of kilometres driven by trucks
- Reduction in emission, noise and pollution in city centres
- Reduction of the congestion problems near the construction site
- Reduction in materials used due to less damaged and stolen materials
- Reduction in the over-ordering of materials

These potential benefits have to be weighed against potential costs increases associated with the operation of the CCC. The activities connected to the services provided by the CCCs will be included in the model developed in this research.

4 COST ACCOUNTING 1. MODELS

This chapter provides a summary of financial models for construction logistics explained in the literature. Search terms, “activity-based costing”, “activity-based costing and construction”, and “activity-based costing and construction logistics” are used to prepare a selection of models (partly) applicable for the purpose rendered in this research. Research papers of (Christian & Geiger, 2018), (Yuan Fang & Thomas Ng, 2011), (Back et al., 2000), (Nguyen, Tommelein, & Martin, 2018), And (Liu, Ren, Xu, & Chen, 2015) on topics related to activity-based costing or costs control are included in this chapter. A research paper of (Y Fang, Ma, & Luo, 2018) on the use of activity-based methods for carbon emission modelling for construction logistics is used to develop the model. Bachelor thesis’s of 35, and (Russcher, 2016) are included in this chapter to include the activities of the Construction Consolidation Centre in the model.

Christian and Geiger (2018) identified the best costing method application for improving the effectiveness of management for performance in a construction project. The criteria connected to this application are similar to the goals of this research. To be able to predict the results on the total costs in case logistical solutions as a Construction Consolidation Centre are included in the process. The model must be specific enough to connect costs to specific stages of the process. Christian and Geiger (2018) applied four methods to construction activities being; Production effort unit method, Absorption costing, ABC costing, and marginal costing. A brief summary of the methods described by Christian and Geiger (2018) is written hereafter, for an in-depth explanation of all methods it’s advisable to read the paper of Christian and Geiger (2018).

Production effort unit method

Production effort unit method creates a common measure for the entire production process which can be used in all costing, planning and comparison activities. It’s used to transform a company that produces various products to a company that produces one, to simplify the monetary control. The method consists of the following steps:

- Defining an entity for value measuring;
- Evaluation of all included posts in units;
- Evaluation of resources, allocated in the units (material, equipment etc.); and
- Determining posts in value-adding units to determine the difference between resource consumption of the post and the resource consumption of the base process.

Absorption Costing

Absorption Costing is a procedure in which all costs including fixed and variable costs are treated as product costs. Common costs are split between multiple costs centres in proportion to the estimated benefits received. The method includes four steps in the process:

- Identification of costs centres;
- Identification of support or service costs centres;
- Calculation of the overhead absorption rate (OAR); and
- Use OAR to calculated overhead costs per unit.

Activity-based costing

Activity-based costing is a slightly more complex and costly method, however, adopted by many industries. The process steps include:

- Identification of activities and processes, and creation of process flowcharts;
- Assignment of resource costs to activities;
- Tracing of all secondary activities to primary activities;
- Identify which costs objects are to be priced;
- Multiply the activity recovery rates by the quantity of output consumed as specified in the bill of activities; and
- Direct costs and non-traceable costs should be added to the costs to give the total costs of the costs object.

An advantage of this method compared to traditional costs management methods is the prevention of distortion of the costs. The activity-based costing method could be used to make a qualitative analysis of the operation, detect the valueless operations and then improve the process (Liu et al., 2015).

Marginal costing

Marginal costing treats the variable costs as costs units and fixed costs of the period are written off against the aggregated contribution of the project. The method consists of the following steps:

- Fixed costs and variable costs are separated;
- Variable costs in the products are allocated;
- The contribution margin of a product will be calculated; and
- Profit of the project consists of the total contribution margin minus the fixed costs.

After testing all four methods in a construction project in Brazil Christian and Geiger (2018) concluded that the marginal costing method and the Activity-based costing method are applicable in costs management for buildings. The marginal costing method allows managers to evaluate the result of each individual unit in the project. Due to the specific contribution margin of each product. The Activity-based costing model is easy to apply. Considering the intended purpose of identifying the costs per product and redistribution of fixed costs among products, this method is efficient. These methods can be used to identify the costs centres and the activities that cost the most. It generates the opportunity for companies to seek alternative techniques to reduce costs in construction.

Process-based costing model

Nguyen et al. (2018) developed a process-based costing model with the purpose to provide designers with accurate costs feedback for design decisions. They connected an activity-based costing model to the elements for design input included in the building information model. The developed model could show the effect of both products as well as process changes on the total costs of the project. The model developed in this paper is focussed on the impact of process changes by logistical innovations on the costs of projects with a finalized design. The output of this model could produce a costs database for activities involving the construction consolidation centre. The developed process map of the activity-based model is similar to the model produced by Yuan Fang and Thomas Ng (2011).

In this research, however, the innovations are focussed on changes in the logistical process and not necessarily changes in the products used in the project or the final design of the building. The marginal costing method and the process-based costing model which are focussed on the contribution margin of all products and product changes are for that reason not an applicable starting point for the development of a new model. The activity-based model is applicable due to its focus on assigning costs to the activities. Yuan Fang and Thomas Ng (2011) state that by using the activity-based costing approach, the resources consumed can be traced back to the consuming activity and subsequently to a particular costs element. Back et al. (2000) mention activity-based costing as an essential analytical tool for understanding the relationship between cycle time and costs for any process under examination. This tool will help construction companies who are continually endeavouring to improve the efficiency and effectiveness of their operations to fully understand the behaviour of their processes.

Yuan Fang and Thomas Ng (2011) developed an activity-based model for costs calculations of the logistical process for a supplier of precast concrete walls. The developed activity scheme of this process is shown in Figure 9.

The four steps in their process are:
- Assigning and analysing activities;
- Gathering costs data and tracing costs to activities;
- Establishing outputs; and
- Identifying the activity drivers and analysing the costs.

The process described by Yuan Fang and Thomas Ng (2011) however is a linear process for cost accounting of a single process. In their paper on carbon emission modelling for construction logistics process (Y Fang et al., 2018) stress the need for activity selection and the influence of process management by the contractor on this process. The process scheme as shown in Figure 9 will be supplemented with the extra activities resulting from the construction consolidation centre. The process for which the model will be used will result in the costs for each activity and could result in skipping stages like stocking at intermediate warehouses or on-site buffer stocks.

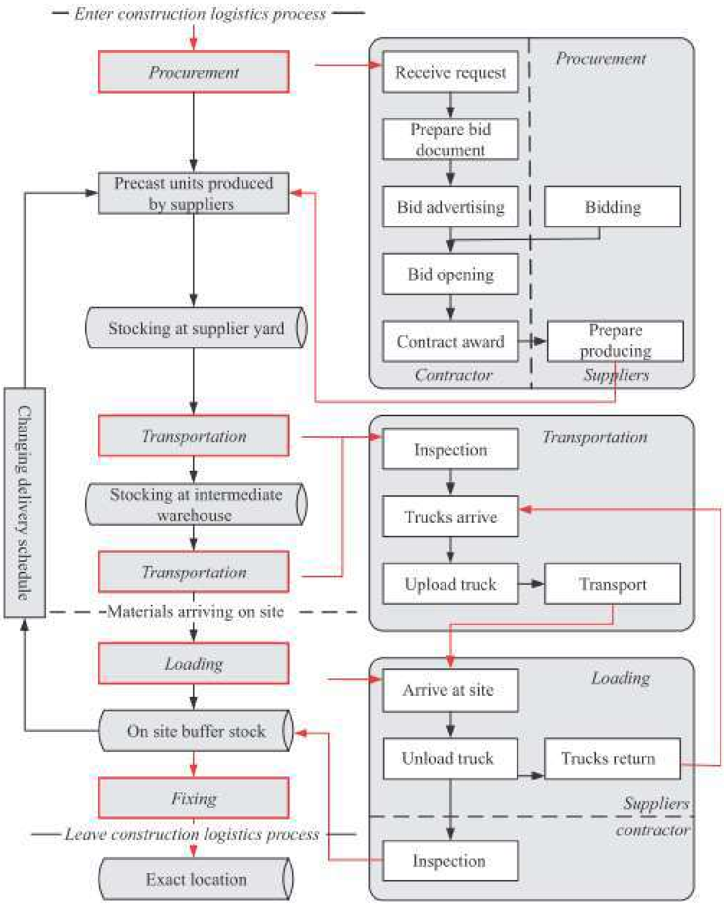


Figure 9. Activity scheme Yuan Fang and Thomas Ng (2011).

If changes need to be made for process development, such as the implementation of a construction consolidation centre it suggested by Back et al. (2000) to add the following steps to the process:
- Develop process improvement strategies;
- Modify the process model;
- Verify and validate the new proposed model; and
- Evaluate the time and costs impact of the proposed process changes.

Improvements in one activity will clearly have an impact on the processing time, however, it's unrealistic to expect that processes common to engineering operations can be described with only linear relationships. Process improvements in one activity could lead to a new set of options later on in the process or could impact processes durations. It could be argued that analysis like these ones is often complicated by the stochastic character of the involved activities. However, enabled by computer simulation, it is still possible to examine these processes and experimentally modify them to test process changes contemplated by the companies (Back et al., 2000).

Costs occurring in a process depends upon the activities and the resources consumed in these activities. There are five categories for these resources, namely, labour, materials, equipment, facilities, property and capital (Kaplan & Cooper, 1998). The type of costs described in this chapter composed of these five resource categories. The formulas in the figures in this chapter are based on the model of Yuan Fang and Thomas Ng (2011) the light blue text is changed based on the papers mentioned in the text.

Procurement costs are the expenses associated with the sourcing of suitable suppliers for the construction project. This process involves identifying appropriate suppliers, seeking quotations from suppliers and negotiating the contractual terms (Yuan Fang & Thomas Ng, 2011). Compared to industrialised sectors in which percentages are used to calculate procurement costs these are not accurate enough for construction projects. Each project is unique, and the materials and techniques used vary. Consequently, the procurement costs included in the model is calculated with the hours spent by the procurement department on the project, as well as the office equipment being used to facilitate the process (Yuan Fang & Thomas Ng, 2011). The formulas used in the development of the activity-based costing model are shown in
Figure 10.

Logistics process	Category	Resource	Costs of resource	Costs of activity
Procurement	Labour	Staff in bidding	Pay rate	Pay rate × working time
	Equipment	Printer, paper fax, telephone	Depreciation rate	Depreciation rate × contract price
	Capital	Travel costs	Travel costs rate	Travel costs rate × contract price

Figure 10. The procurement costs of the construction process (own. illustration based on the model of Yuan Fang and Thomas Ng (2011)).

The delivery process of materials or elements etc. requires proper planning from the involved companies. Personnel of the contractors and sub-contractors are used to their traditional way of working and changes in this process will require time to adjust. The results from interviews with a project manager conducted by Kroon (2018) showed that the extra link in the chain of communication resulted in extra hours spent by the project manager. Solving the problem of missing materials also led to extra hours spent. The project manager mentioned that he expected this to become less by experience however, the costs will be included in the model. The formulas used in the development of the activity-based costing model are adjusted from the model for procurement made by Yuan Fang and Thomas Ng (2011). The formulas are shown in Figure 11.

Logistics process	Category	Resource	Costs of resource	Costs of activity
Process management	Labour	Staff in process management	Pay rate	Pay rate × working time
	Equipment	Printer, paper fax, telephone	Depreciation rate	Depreciation rate × contract price
	Capital	Travel costs	Travel costs rate	Travel costs rate × contract price

Figure 11. The process management costs of the construction process (own. illustration based on the model of Yuan Fang and Thomas Ng (2011)).

Inventory costs are an operating cost resulting from the keeping of stocks in a warehouse and the maintenance of this warehouse. The definition of Inventory costs in this paper is adopted from Yuan Fang and Thomas Ng (2011). In their research, they used the work of (Gürmann & Schreiber, 1990) and (Waters, 1996) to develop a formula for cost calculation of storage at the supplier's yard and at intermediate warehousing. Costs for inventory at the supplier's yard is composed of the administration, handling, and frozen capital costs. Costs for intermediate warehousing is composed of rent and frozen capital costs. The decision for inventory building is based upon the type and size of materials and the expected delivery schedule. In case a Construction Consolidation Centre is added to the process, stakeholders involved are required to decide if on storage in the Consolidation Centre is necessary and desirable. The formulas used in the development of the activity-base costing model are shown in Figure 12.

Logistics process	**Category**	**Resource**	**Costs of resource**	**Costs of activity**
Storage at supplier yard	Labour	Worker (handling)	Pay rate	Pay rate × total quantity
		Administrator	Pay rate	Pay rate × storage quantity × unit costs × duration
	Equipment	Handling truck	Rental rate	Rental rate × total quantity
		Iron Material	Depreciation rate	Depreciation rate × total quantity
	Material	Stow-wood	Depreciation rate	Depreciation rate × storage quantity × unit costs × duration
	Capital	Opportunity costs frozen in inventory	Rental rate	Opportunity costs rate × duration × storage quantity × unit costs × duration
Storage at intermediate warehouse	Capital	Rent	Rental rate	Rental rate × storage quantity × unit costs × duration
		Opportunity costs frozen in inventory	Opportunity costs rate	Opportunity costs rate × storage quantity × unit costs × duration
Storage at Construction Consolidation Centre	Labour	Worker (handling)	Pay rate	Pay rate × total quantity
		Administrator	Pay rate	Pay rate × storage quantity × unit costs × duration
	Equipment	Handling truck	Rental rate	Rental rate × total quantity
		Iron Material	Depreciation rate	Depreciation rate × total quantity
	Material	Stow-wood	Depreciation rate	Depreciation rate × storage quantity × unit costs × duration
	Capital	Opportunity costs frozen in inventory	Rental rate	Opportunity costs rate × duration × storage quantity × unit costs × duration

Figure 12. Inventory costs of the construction process (own. illustration based on the model of Yuan Fang and Thomas Ng (2011)).

Transportation costs are related to the travel distance between the production location and the construction site, costs included are the wages of the drivers, equipment costs and in-transit inventory costs (Yuan Fang & Thomas Ng, 2011). Part of quality control dependent on the material transported could include inspections of the load. If quality checks are included in the process wages of inspectors need to be included as well. Contractual agreements between suppliers and contractor could include penalties for delayed deliveries of just-in-time delivery. Those costs are included in the transportation costs as well. The formulas used in the development of the activity-based costing model are shown in Figure 13.

Logistics process	Category	Resource	Costs of resource	Costs of activity
Transportation (to CCC)	Labour	Truck driver	Pay rate	Pay rate x total quantity × distance
		Inspector	Pay rate	Pay rate × delivery times
	Equipment	Truck	Rental rate	Rental rate x total quantity × distance
	Material	Stow-wood	Depreciation rate	Depreciation rate × total quantity
		Iron material	Depreciation rate	Depreciation rate × total quantity
Transportation (to the intermediate warehouse)	Labour	Truck driver	Pay rate	Pay rate × total quantity × distance
		Inspector	Pay rate	Pay rate × delivery times
	Equipment	Truck	Rental rate	Rental rate × total quantity × distance
	Material	Stow-wood	Depreciation rate	Depreciation rate × total quantity
		Iron material	Depreciation rate	Depreciation rate × total quantity
Transportation (to the construction site)	Labour	Truck driver	Pay rate	Pay rate × total quantity × distance
		Inspector	Pay rate	Pay rate × delivery times
	Equipment	Truck	Rental rate	Rental rate × total quantity × distance
	Material	Stow-wood	Depreciation rate	Depreciation rate × total quantity
		Iron material	Depreciation rate	Depreciation rate × total quantity
	Capital	Penalty	Penalty rate	Penalty Rate × total quantity

Figure 13. Transportation costs of the construction process (own. illustration based on the model of Yuan Fang and Thomas Ng (2011)).

The costs for site storage is included in the process in case materials need to be temporarily stored on-site before being fixed into the designated place in the project(Yuan Fang & Thomas Ng, 2011). Site storage costs include, for example, the materials used to keep the delivered goods in place and the depreciation rate of these materials, and the opportunity costs frozen in the on-site stocking of materials. It will also negatively impact the costs of loading and on-site transportation costs. The formulas used in the development of the activity-based costing model are shown in Figure 14.

Logistics process	**Category**	**Resource**	**Costs of resource**	**Costs of activity**
On-site storage	Material	Stow-wood (stocking	Depreciation rate	Depreciation rate × storage quantity × unit costs × duration
	Capital	Opportunity costs frozen in on-site stocking	Opportunity costs rate	Opportunity costs rate × storage quantity × duration × unit costs × duration

Figure 14. Costs for site storage (own. illustration based on the model of Yuan Fang and Thomas Ng (2011)).

Costs of loading and on-site transportation are a result of the movement of materials on the construction site (both horizontally as vertically), from the time point of arrival(unloading) till the final location just before fixing in case of materials or during the process of fixing with larger elements. It's dependent on the process of how high these costs will be, moving materials several times due to on-site storage, for example, will increase the costs of on-site transportation. The formulas used in the development of the activity-based costing model are shown in Figure 15.

Logistics process	**Category**	**Resource**	**Costs of resource**	**Costs of activity**
Loading and on-site transportation	Labour	Worker (handling)	Pay rate	Pay rate × total quantity
		Truck driver (waiting)	Pay rate	Pay rate × total quantity
	Equipment	Crane	Rental rate	Rental rate × total quantity
		Truck	Rental rate	Rental rate × total quantity
	Material	Iron material/pallets etc. (handling)	Depreciation rate	Depreciation rate × total quantity

Figure 15. Costs for loading and on-site transportation (own. illustration based on the model of Yuan Fang and Thomas Ng (2011)).

The costs of fixing the materials are case-specific. In the case with precast concrete walls described by Yuan Fang and Thomas Ng (2011) the on-site transportation and fixing in place was done by the same construction workers in one process. In the research of Russcher (2016) the on-site transportation of tiles etc. was done by a specialized team of logistical employees. The fixing of the tiles was done by a different group of specialists with a different pay rate. In the development, these costs will be separated to enable the usage of the model in the largest number of cases. The formulas used in the development of the activity-based costing model are shown in Figure 16.

Logistics process	**Category**	**Resource**	**Costs of resource**	**Costs of activity**
Fixing	Labour	Worker (fixing)	Pay rate	Pay rate × total quantity
	Equipment	Crane	Rental rate	Rental rate × total quantity
	Material	Tools (fixing)	Depreciation rate	Depreciation rate × total quantity

Figure 16. Costs for fixing (own. illustration based on the model of Yuan Fang and Thomas Ng (2011)).

A new activity-based costing framework is developed with the input of the literature described in the previous chapters. The starting point is the existing model for activity-based costing in construction logistics developed by Yuan Fang and Thomas Ng (2011). Extra processes caused by the implementation of a Construction Consolidation Centre are added to the model. As a result of previous research extra cost types are included as well. The logistics process and included activities are shown in Figure 17 and Figure 18.

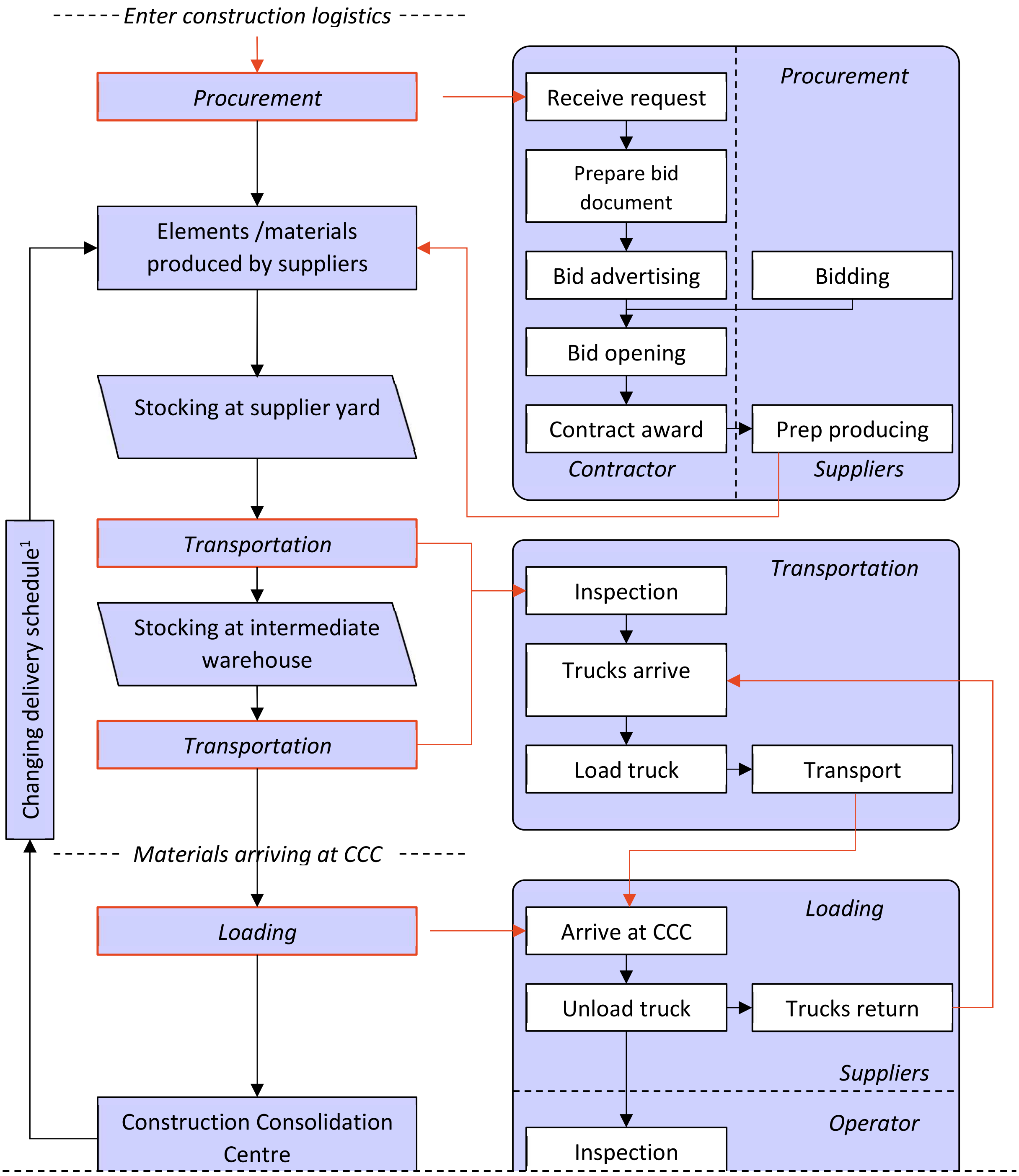


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Figure 17. Logistics process and activities of construction material acquisition with CCC part 1 (own illustration)

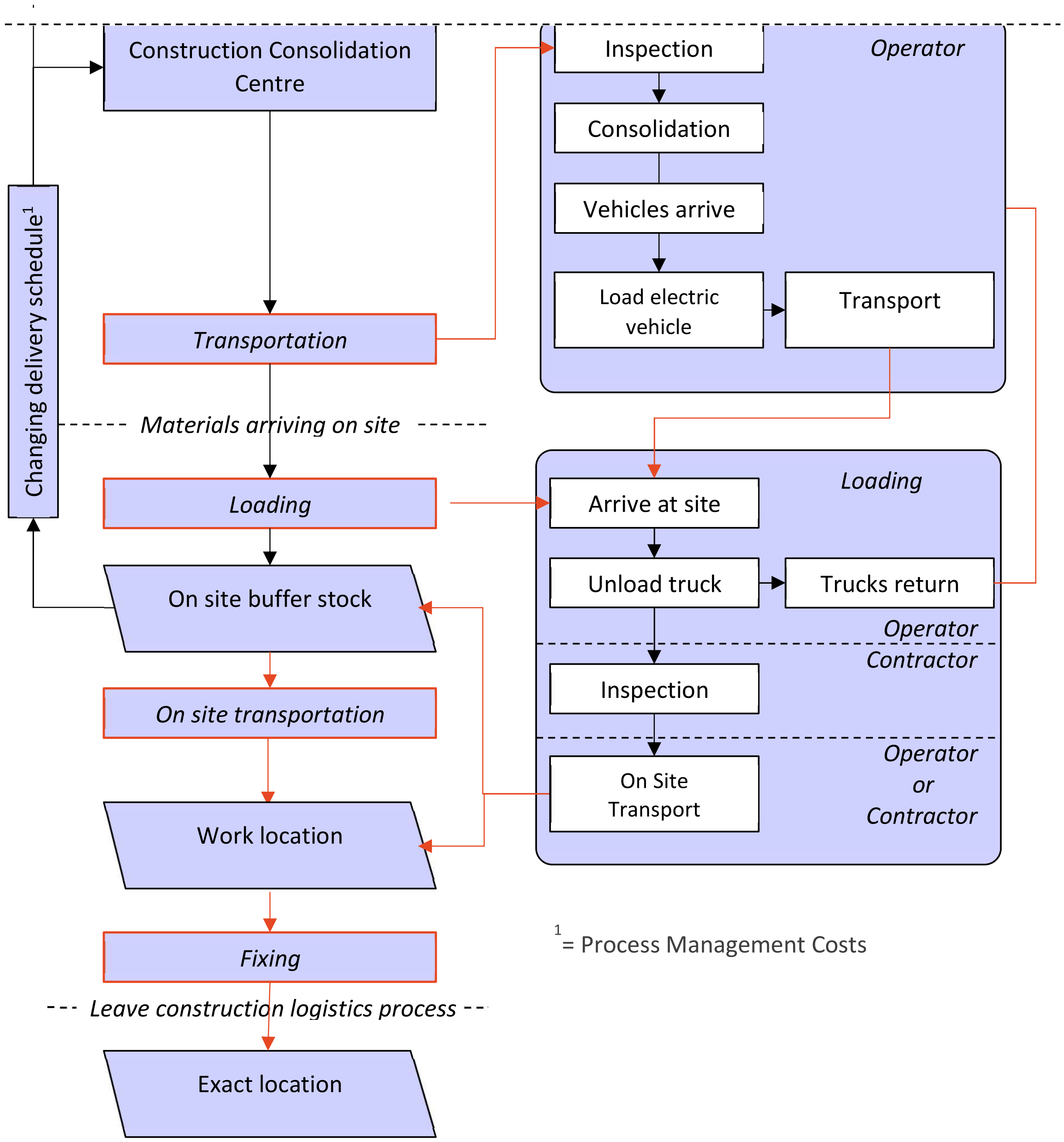

Figure 18. Logistics process and activities of construction material acquisition with CCC part 2 (own illustration)

The developed framework contains all activities in the logistical process from production until the exact position on site. All activities are modelled in excel and used as a starting point for the empirical research described in the next chapter.

EMPERICAL RESEARCH

Part IV

5 MODEL DEVELOPMENT 1. CASE INTRODUCTION

The history of international Construction Consolidation Centres is described in the previous chapters. Companies in the Netherlands followed these international examples in the development of Dutch CCCs. The Construction Consolidation Centre in Nieuwegein near the city of Utrecht is one of the first CCC developments in the Netherlands. The location is operated by Volkerwessels Bouwmaterieel. The Hub opened for the project "The trip" in the city of Utrecht. The service provided consisted of the consolidation of materials and delivery with higher truckload, in time delivery to the site without waiting times, runners on site for delivery of materials to the right working place. The hub Nieuwegein is closed and a new location in Utrecht is opened.

Bouwhub Utrecht

The Bouwhub Utrecht (see Figure 19) is intended to be a permanent location in the periphery of the city of Utrecht. The CCC provides services to multiple sites with multiple landlords. It is currently the only CCC operated by Volkerwessels in the city of Utrecht. Using the CCC is voluntarily for contractors and the CCC is initiated by the private sector. The focus area of the CCC is the city of Utrecht, however, projects in other cities are supported as well. The CCC is operational and provides services to a diverse spectrum of contractors building in neighbouring cities. The operator is currently working with costs plus a percentage fee contracts. This means that a contractor knows what the costs of the services are, and the total price depends on how often the services are used. Increased questions to predict the costs of the CCC for a project in advance and the wish of the CCC to also show their benefits are the incentives to measure all their activities.

Figure 19 Bouwhub Utrecht (Volkerwessels.nl)

The current activities of the HUB consist of;

Logistics coordination

Organising transport from the CCC to the site in collaboration with transport companies.

Just-in-time delivery

If necessary, the delivery of goods from the CCC to the site can be done within specific time slots.

Buffer storage

The hub operates with a buffer time of approximately 3 weeks in between deliveries of suppliers to the CCC and deliveries from the CCC to the construction sites.

Warehousing

Storage space is used for storage of larger elements for suppliers that lack storage space on production location.

Express transport

The Hub owns an electric car for express delivery of last-minute orders by contractors.

The operator of the Bouwhub Utrecht provided their services in several projects. TNO and student researchers managed to monitor (parts) of these projects (De Bes et al., 2018). The theoretical model developed in this research is extended with the available information provided in these reports and documents provided by the operator of the Bouwhub Utrecht.

De Trip Utrecht

Project de Trip consists of a collective of three buildings. The project is located in Rotsoord a neighbourhood of Utrecht. A total of 253 apartments for both the social and private rented sector and approximately 1500 m2 of commercial space are divided over these three buildings.

The project is developed by Jebber a local developer and constructed by contractor Boele & van Eesteren a Volkerwessels company. The project was finished in 2016.

Figure 20 De Trip Utrecht (jebber.nl)

Voortzetgebouw Utrecht

One of the well-known shopping malls in the Netherlands, Hoog Catharijne got a new entrance building. Approximately 13 thousand m2 shopping and office area was added. The building is located on the same square as the Noordgebouw. It is constructed by Boelen & van Eesteren commissioned by Klépierre. The first phase of the project was finished in 2018.

Figure 21 Voorzetgebouw Utrecht (Boele.nl)

Noordgebouw Utrecht

A multifunctional building right in the heart of Utrecht. By its designers, the building is described as a new Urban Hub. The building is a place for people to live with 16 apartments. The hotel with approximately 160 rooms a restaurant, bar and wellness provide the opportunity for a short stay. Offices with meeting spaces provide a place to work and a part of the building is reserved for retail. The building has a direct entrance to the central station that is open for public.

The project is developed by a consortium of developers Vorm ontwikkeling and Dura Vermeer Vastgoed. The building is constructed by contractor Dura Vermeer and was finished in 2019.

Figure 22 Noordgebouw Utrecht (cu2030.nl)

Transport

TNO reported that all projects that used the CCC Utrecht showed reductions in the number of journeys to the construction site. Project De trip had a reduction of 47% in journeys and saved 25% if measured in kilometres. In project Voortzetgebouw a reduction of 47% was measured. In this project, only 9% of all deliveries came via the CCC, because the agreements to use the CCC were not always complied with by the contractor. The Noordgebouw project showed the highest reduction in journeys of 77% for al journeys via the CCC that was part of the supply of work packages. The materials supply directly organised by the suppliers via the CCC showed a reduction of 19% in journeys (De Bes et al., 2018). These results show the benefits of the CCC and the enormous reduction when the full potential of the CCC is used. Including the impact on transport costs in the model requires several formulas described hereafter.

Journeys and load factor

The number of journeys needed to deliver the materials to the site depends on three factors. The total freight is project-related input and requires information about the building. The truck capacity is related to the chosen truck and its costs components can be generated from a generic costs database. The load factor of transport can be measured in weight in case of large prefabricated and heavy elements. In the fixing stage of a project, the load factor is measured in space usage in the truck. In traditional construction projects, the average load factor of transport to a construction site is 40% (Merriënboer & Ludema, 2016). One of the benefits of implementation of a CCC in the construction process is the increase in the load factor of trucks due to better coordination and consolidation. In project Voortzetgebouw the load factor measured for transport to the CCC was 66% and from the CCC to the site was 78%. This project only used the services for consolidation and did not work with day packages of bundled materials. In project Noordgebouw the supply chain was split into the supply of materials organised by the suppliers and the supply of day packages organised by the operator of the CCC. The supply chain of day packages consisted of 82% of the total transport and had a load factor of 84% from the CCC to the site. An important note is that the process was optimized for day production on-site and no extra storage on-site which resulted in extra journeys. The supply chain organised by suppliers achieved a load factor of 58% for transport to the CCC and 77% from the CCC to the site (De Bes et al., 2018). The number of journeys is calculated with the following formula:

$$Journeys = Total\ freight * Truck\ capacity * Load\ factor$$

Costs related to transport

The factors explained before are part of the costs related to transporting. The transport distances are project-related input data and depend on the location of the supplier and the construction site. The average speed of the trucks depends on the type of truck and the route. The costs of the journey are calculated with the rental price of the truck including the costs of fuel and wages of the driver. The transport costs in the process including the CCC and the traditional process are calculated with the following formulas:

$$Cost\ transport\ traditional = \frac{Distance\ supplier\ to\ site}{Speed} * Cost\ journey * Journeys$$

$$Cost\ transport\ supplier = \frac{Distance\ supplier\ to\ CCC}{Speed} * Cost\ journey * Journeys$$

$$Cost\ transport\ operator = \frac{Distance\ CCC\ to\ site}{Speed} * Cost\ journey * Journeys$$

Figure 23 shows the costs related to transport as part of the model developed for the calculations. Savings in costs and distance can be calculated by subtracting the costs in the new process from the traditional process.

Cost related to Transport in the traditional process				
Supplier > site	90	Km	1,50	h
Load factor	40	%	12	load carrier
Journeys	19,0	st.	1710	km
1. Transport cost	**€ 2.280,00**			

Cost related to Transport for process including CCC				
Supplier > CCC	90	Km	1,50	h
Load factor	90	%	28	load carrier
Journeys	8,0	st.	720	km
2. Transport cost	**€ 960,00**			
CCC > site	10	Km	0,33	h
Load factor	90	%	28	load carrier
Journeys	8,0	st.	80	km
3. Transport cost	**€ 213,33**			

Figure 23 Transport costs as part of the model.

The first costs factor contains the costs related to transporting time as described before. The other components related to trucks are the time that trucks including drivers are being loaded or unloaded and the time that trucks are waiting before this process can start.

Unloading and loading time

The unloading time at the CCC was measured in two projects. The first project Noordgebouw had an average unloading time of 26 minutes in the second project Voortzetgebouw, the unloading time was 11 minutes. The big difference in loading time can be explained by the lower load factor in the Voortzetgebouw project (De Bes et al., 2018). The average loading time at the CCC was 32 minutes for the Voortzetgebouw project and 8 minutes for the Noordgebouw project. The reason for this difference is the use of load carriers on wheels in the Noordgebouw project, which made loading easier (De Bes et al., 2018). The time for loading the trucks at the CCC took 16 minutes and 35 seconds for the process of the tiler and the metal stud wall supplier in the Noordgebouw project Kroon (2018). The new process includes an extra unloading and loading step at the CCC in comparison to the traditional process. The new process, however, has a reduced number of journeys due to higher load factors.

The costs of a truck being (un)loaded is calculated with the following formula. The process of unloading itself is not included in this formula. These costs are part of the handling costs at the CCC and the unloading costs on-site.

$$Cost\ loading = Time\ loading * Cost\ journey * Journeys$$

A fragment of the developed model can be seen in Figure 24. The savings on loading costs related to the trucks are calculated by subtracting the costs in the new process from the traditional process.

Cost related to loading/unloading in the traditional process			
Supplier > site	1,0	h/journey	19 h
4. Loading cost	**€ 1.520,00**		

Cost related to loading/unloading for process including CCC			
Supplier > CCC	1,0	h/journey	8 h
5. Loading cost	**€ 640,00**		
CCC > site	0,5	h/journey	4 h
6. Loading cost	**€ 320,00**		

Figure 24 Loading costs as part of the model.

Waiting time

In the traditional construction process without coordination of arrival of trucks, on-site trucks need to wait before unloading. Reasons can vary from waiting for another truck, availability of cranes, coordination with personal on-site for a place to store the unloaded materials etc. In the Noordgebouw project, the waiting time in a process including the CCC was measured, on average for the total process this time was 9 minutes a reduction from the traditional 23 minutes, when specifically looked at the waiting time for transport in the fixing stage the waiting time was only 2 minutes on-site. Waiting time at the CCC was 3 minutes in project Voortzetgebouw and 4 minutes in project Noordgebouw (De Bes et al., 2018).

The costs related to waiting trucks before unloading are calculated with the following formula:

$$Cost\ waiting = Time\ waiting * Cost\ journey * Journeys$$

Figure 25 shows a fragment of the model that contains the costs related to the time trucks are waiting in the traditional and the process including the CCC. The optimization results in reduced waiting times and a reduction in journeys, resulting in savings on the costs related to waiting.

Cost related to waiting of trucks in the traditional process			
Supplier > site	0,5	h/journey	9,5 h
7. Waiting cost	**€ 760,00**		

Cost related to waiting of trucks for process including CCC			
Supplier > CCC	0,05	h/journey	0,4 h
8. Waiting cost	**€ 32,00**		
CCC > site	0,00	h/journey	0 h
9. Waiting cost	**€ 0,00**		

Figure 25 Wating costs as part of the model.

Implementation of the CCC in the process adds a few new activities to the process related to storage, handling and consolidation into work packages. These activities are conducted at the CCC location and are support activities for the optimization of the logistical process to the site and on-site.

Costs related to handling at the CCC

The handling costs at the CCC is the first type of costs as a result of implementing the CCC in the process. The costs related to unloading incoming transport, storing the freight and loading outgoing transport at the CCC Utrecht are standardized for every load carrier. Included labour costs are based on two employees for loading and one inspector. Included materials are forklift of different types depending on the weight of the load. The price of every activity is fixed. The Costs for handling at the CCC is calculated with the following formula:

$$Cost\ handling = Loadcarrier * Fixed\ price$$

The implementation of the handling costs in the developed model can be seen in Figure 26.

Cost in the traditional process	*Cost related to handeling at the CCC*		
	Handling cost	€ 5,00	/load carrier
	10. Handling cost	**€ 1.110,00**	

Figure 26 Handling costs at the CCC as part of the model.

Costs related to storage at the CCC

The second type of costs at the CCC is the storage costs. Adding buffer storage at the CCC is required to enable suppliers to deliver with high load factors and combine materials of different suppliers for transport to site. The costs for buffer storage of materials is calculated for square meters of the load carrier. The fixed price per day includes the costs of the secured storage facility. The storage time in days is project-related input data and depends on the project planning and fixing speed on-site. The costs for storage at the CCC is calculated with the following formula:

$$Cost\ storage = Space\ loadcarrier * Cost\ per\ day * Days$$

Figure 27 shows the storage costs at the CCC implemented in the developed model.

Cost in the traditional process	*Cost related to storage at the CCC*			
	Storage cost	€ 0,40	/day	€ 2,00 /week
	Storage cycle	2	weeks	10 days
	11. Storage cost	**€ 888,00**	€	
	Storage cycle	3	weeks	15 days
	11. Storage cost	**€ 1.332,00**	€	

Figure 27 Storage costs at the CCC as part of the model.

Consolidation into work packages at the CCC

The third type of costs at the CCC is the costs related to consolidation into work packages. Order picking at the CCC Utrecht was measured in student research by Kroon (2018) for project Noordgebouw. The order picking process for a tiler and a metal stud wall supplier was timed in the CCC for a couple of weeks. The average production times a day and for one load carrier differed a lot. It depends on the demand from the supplier for a day's production and the number of different materials on the load carrier. The average time for order picking the materials for a tiler was 19minutes and 50 seconds for the process of a metal stud wall supplier the process took 20 minutes and 28 seconds. In this project, the tiler worked with a crew of four with an average speed of 0,88m^2 an hour per worker. The metal stud wall supplier worked with a different crew every day with an average production speed of 1,62m^2 an hour per worker.

The costs related to consolidation and creating work packages at the CCC is calculated with the following formula. The total number of days is dependent on the planning for the fixing stage of the project including the suppliers. Consolidation time per day is highly dependent on the material quantity and the type of materials (project-related input data). The pay rate of CCC staff is part of the standard costs figures.

$$Cost\ consolidation = Total\ days * Time\ consolidation * Number\ of\ staff * Pay\ rate\ staff\ CCC$$

The costs related to the consolidation in day packages can be seen in Figure 28.

Cost in the traditional process	*Cost related to consolidation at the CCC*		
	Planning Fixing	113 weeks	563 days
	Pay rate staff CCC	€ 35,00 /h	2 n staff
	Consolidation	0,3 h/day	
	Time	187,7 h	
	12. Consolidation cost	**€ 13.139,58**	

Figure 28 Consolidation costs at the CCC as part of the model.

Labour productivity

The effect of logistical innovation with runners on-site on labour productivity is researched by multiple students. Russcher (2016) conducted a case study of a project in Almere, The Netherlands. In this research, the effect on the productivity of a tiler was measured. The costs for tiling in this project was €35/m^2 and the part of the costs for labour was €11,69. The supplier calculated with a discount of €1/m^2 because of the runners which are 37 minutes and 49 seconds a day when expressed in time. The research showed that occasionally the tiler needed to get materials from a different room because the logistical crew could not put the materials in the correct room due to obstacles in the corridors. A process without those mistakes could have saved the tiler approximately 6 minutes a day which translates to €0,17/ m^2.

Labour productivity was measured in the project The Trip by Stoffels (2016). She measured the impact on labour productivity for metal stud walls, wooden frames, plasterwork of walls, steel frames, wall tiles and kitchens. She excluded floor tiles and toilet facilities because those aspects were subject to change. Calculating increased labour productivity was done by comparing the traditional process of a supplier organising their own materials and labour with a process including the CCC for the logistics of materials and the supplier for the fixing of the materials. Only the process for plasterwork of walls, wall tiles and kitchens could be compared due to a lack of traditional measurements. In the case of the plasterwork for walls (15%) and kitchens (31,1%), the productivity measured in hours increased. In the wall tiles, the productivity measured in hours decreased by 8,5%. Measured in euros the process was cheaper for al materials due to a lower wage for the logistical crew than the specialist labour workforce in the process. The exact differences can be seen in Appendix G.

The labour productivity is measured for the tilers and metal stud wall supplier in project Noordgebouw by Kroon (2018). The process including the CCC resulted in a 25% increase in labour productivity for the tiler resulting in 2 hours and 30 minutes of extra production time for each employee. In the process of the metal stud wall supplier, a 21,3% increase was measured resulting in an increase of 2 hours of production time for each employee. The approach for this research and the results can be seen in appendix H.

Labour productivity is included in the developed model as part of the activities on site. The time needed on-site to unload, transport and fix the material in the traditional process in comparison with the process including the CCC is the increase in productivity.

Unloading on-site

The first aspect related to the activities on-site is the unloading of the arriving trucks by the employees of the subcontractor in the traditional process or the specialized team in the process including the CCC. The process of the CCC Utrecht is measured in project Noorgebouw by Kroon (2018). The time for unloading a truck on-site by a crew of the CCC took 13 minutes and 54 seconds on average. The details of the calculation and the comparison to the traditional process can be seen in more detail in appendix H.

The costs related to unloading on-site are calculated with the following formulas. This factor does not include the costs for the truck and equipment like cranes provided by the main contractor.

$$Cost\ unloading\ supplier = Number\ of\ days * Time\ unloading * Number\ of\ staff * Pay\ rate\ staff\ supplier$$

$$Cost\ unloading\ operator = Number\ of\ days * Time\ unloading * Number\ of\ staff * Pay\ rate\ staff\ operator$$

The costs of unloading on-site as part of the model can be seen in Figure 29. The difference in production days is a result of the productivity in fixing explained in the last step of the model.

Cost for unloading on-site in the traditional process			
Planning Fixing	136	weeks	680 days
Pay rate staff supplier	€ 40,00	/h	1 times a day
Unloading	0,75	h/day	1 n staff
Time	510	h	
13. Unloading cost	**€ 20.400,00**		

Cost for unloading on-site for the process including CCC			
Planning Fixing	113	weeks	563 days
Pay rate runners	€ 30,00	/h	1 times a day
Unloading	0,2	h/day	2 n staff
Time	112,6	h	
14. Unloading cost	**€ 6.757,50**		

Figure 29 Costs of unloading on-site as part of the model.

On-site transport

The transport on-site is part of the logistical chain and is measured during the Noordgebouw project for a process including the CCC. On-site transport to the final position for fixing the materials took 8 minutes and 20 seconds for each load carrier(Kroon, 2018). The calculation and the comparison of the traditional process to the process including the CCC can be seen in more detail in appendix H and I.

The costs related to on-site transport of materials from the truck to the work location are calculated with the following formula. Equipment such as lifts and cranes provided by the main contractor are excluded for the formula because they are used in the traditional process and the process including a CCC.

$$Cost\ transport\ on\ site\ supplier = Number\ of\ days * Time\ running * Number\ of\ staff * Pay\ rate\ staff\ supplier$$

$$Cost\ transport\ on\ site\ operator = Number\ of\ days * Time\ running * Number\ of\ staff * Pay\ rate\ staff\ operator$$

The costs for on-site transportation is included in the model can be seen in Figure 30. The traditional process is based on one staff member of the supplier that is responsible for on-site transport in the new process the on-site transport will be done by a crew of two runners.

Cost for on-site transport in the traditional process			
Pay rate staff supplier	€ 35,00 /h		680 days
On-site transport	2 h/day		1 n staff
Time	1360 h		
15. Running cost	**€ 47.600,00**		

Cost for on-site transport for the process including CCC			
Pay rate runners	€ 30,00 /h		563 days
On-site transport	0,23 h/day		2 n staff
Time	129,5 h		
16. Running cost	**€ 7.771,13**		

Figure 30 Costs of on-site transport as part of the model.

Fixing

The final step in the process is the fixing of the materials in place. The quantity of fixed materials in one day differs highly between the type of materials and the size of the staff. Generic costs databases are developed for the fixing stage of various materials in the traditional situation. One example is bouwkosten.nl developed by Cobouw. These databases contain fixing productivity in days depending on project types, crew size and type of material (Bouwkostenonline, 2020). The costs for fixing are calculated with the following formula:

$$Cost\ of\ fixing = Number\ of\ days * Time\ fixing * Number\ of\ staff * Pay\ rate\ staff\ supplier$$

The fixing staff is required to do the unloading and on-site transport themselves in the traditional process. In the new process, the unloading and on-site transport are done by the runners of the CCC. This results in more fixing time and a higher production per day for the supplier with the same production speed. The planning of the fixing stage for the supplier will be shorter. The costs of fixing as included in the model can be seen in Figure 31.

Cost for fixing in the traditional process			
Pay rate staff supplier	€ 35,00 /h		680 days
Dayproduction	25 m2		
Fixing	13,25 h/day		2 n staff
Time	9010 h		
17. Fixing cost	**€ 315.350,00**		

Cost for fixing for the process including CCC			
Pay rate staff supplier	€ 35,00 /h		563 days
Dayproduction	30,19 m2		
Fixing	16 h/day		2 n staff
Time	9010 h		
18. Fixing cost	**€ 315.350,00**		

Figure 31 Costs of fixing as included in the model.

The researched factors show the potential for factors that can be influenced by implementing the CCC in the process. Activities related to process management, procurement, storage at suppliers and intermediate warehousing have not been researched in the analysed cases. These activities are indirectly related to the operational process influenced by the CCC. No data is gathered for the impact of the implementation of a CCC on these activities and the costs related to these activities, therefor these activities are not tested in the model developed in this research. Conducting research on these aspects is one of the recommendations of this research.

The activities described before display the potential for aspects of the process that can be influenced by implementing the CCC in the process. The impact of implementing a CCC on the activities related to process management, procurement, storage at suppliers and intermediate warehousing has not been researched yet. These activities are indirectly related to the operational process influenced by the CCC. No data is gathered for the impact of the implementation of a CCC on these activities and the costs related to these activities, therefor these activities are not tested in the model developed in this research. Conducting research on these aspects is one of the recommendations for future research. Figure 32 shows the developed model that will be tested in the next step of the research. Figure 33 on page 53 connects the developed model to the initial framework.

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Figure 32 The dashboard of the developed model.

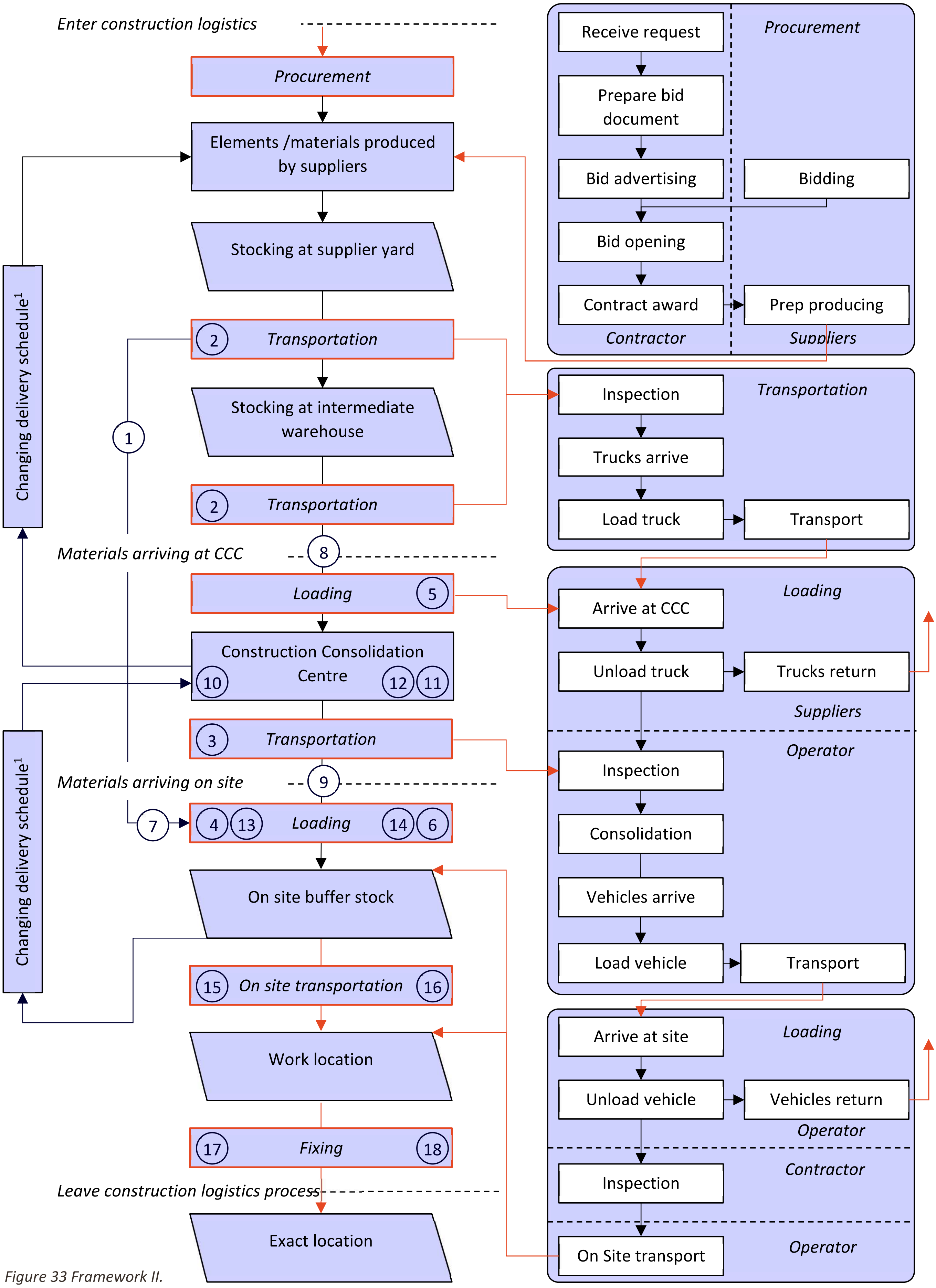

Figure 33 Framework II.

6 MODEL TESTING 1. CASE INTRODUCTION

The model that is developed with the data available in past cases and research, as described in the previous chapter will be tested in a case study in the city of Utrecht, the Netherlands. The area surrounding the train station in the city of Utrecht is undergoing rapid development. Examples of projects are “Het Noordgebouw” and “Voortzetgebouw” explained in the previous chapter, but also the station itself is retrofitted and the final phase of the largest bicycle storage of the world has recently been opened for the public. This list of projects illustrates the finished construction activities however, numerous new projects are currently under development.

One of these new projects is Wonderwoods, located at the Croeselaan a location close by the station and the Jaarbeurs a large conference centre as can be seen in Figure 34. The Jaarbeurs is the building on the bottom of the picture. Wonderwoods is the green building in the middle. The project started with a municipal tender in 2016. The plan called Wonderwoods developed by a consortium of G&S Vastgoed and KondorWessels Projecten was selected by the municipality one year later.

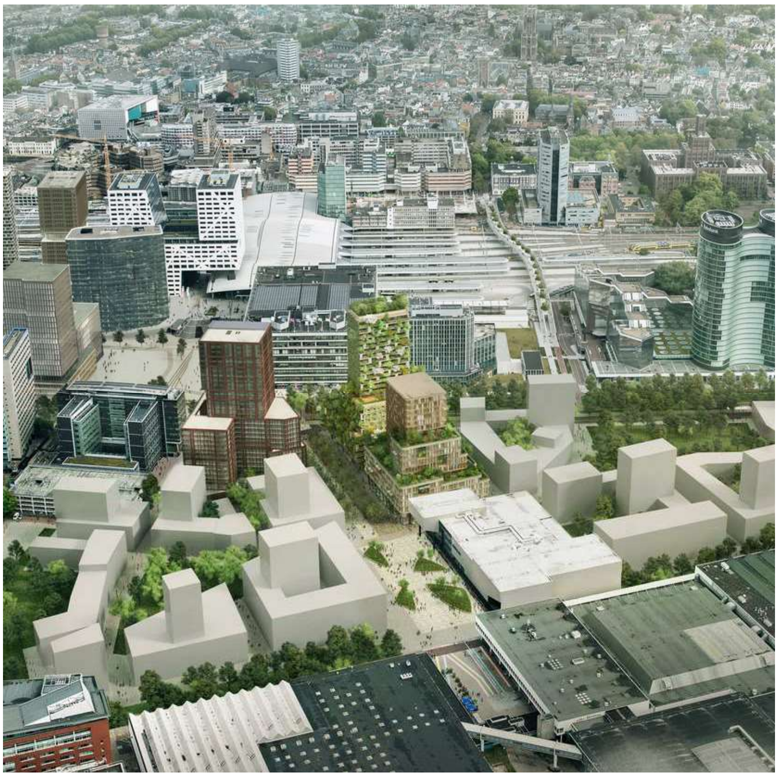

Figure 34 Overview Wonderwoods location (wonderwoods.com)

The design of the building is a result of a collaboration between two architects. Tower 1 is designed by Stefano Boeri Architteti and is based on the design principals of Bosco Verticale Milan. The façade of the building hosts approximately 360 trees and 9640 bushes and plants and can, therefore, be described as a vertical forest. Tower 2 is designed by Roberto Meyer of MVSA Architects and is inspired by the Dutch greenhouses. Nature is brought inside with large indoor gardens and a glass façade that can be opened with good weather.

The program of the building consists of mixed-use. Figure 35 shows the mix of residential(purple), offices(light blue) atrium(yellow), education(dark blue) and smaller functions like technical spaces, bike storages and retail.

Figure 35 Program Wonderwoods (mvsa-architects.com)

Figure 36 Render Wonderwoods (wonderwoods.com)

2. PROJECT PROCESS

In the previous paragraph is described that the project started with a tender in 2016. The developing consortium won this tender in 2017 and is currently selecting a contractor to execute the project. Both companies of the developing consortium are part of the group of VolkerWessels companies. Therefore, the standard procedure is to start the selection procedure by asking contractors within the group to prepare a bid. A brief overview of the project planning can be seen in Figure 37.

The contractor that is selected to prepare a bid starts their process by collecting data about the building. A strategy for the construction process is developed based on the BIM model, technical documents and a list of building specifications etc. The financial part for the bit in this stage of the project is based on experience from previous projects and information provided by suppliers. Which suppliers will get the contract is not yet known in this stage of the project. This will be determined after the project is assigned to the contractor by the developers.

Besides the price for the construction with the traditional supply chain of materials and labour, the contractor was interested in the logistical innovations of the Bouwhub Utrecht. The company operating the Bouwhub Utrecht was asked to provide an indication of the costs involved and the possible benefits of implementing the CCC in the construction process of Wonderwoods. It's the first time that the operator of the hub was asked to provide this overview before the start of the project and got a list of documents from the contractor to base the calculation on. Testing the model developed in this research is combined with this project. The model is tested with the available information provided in the preparation stage of the project.

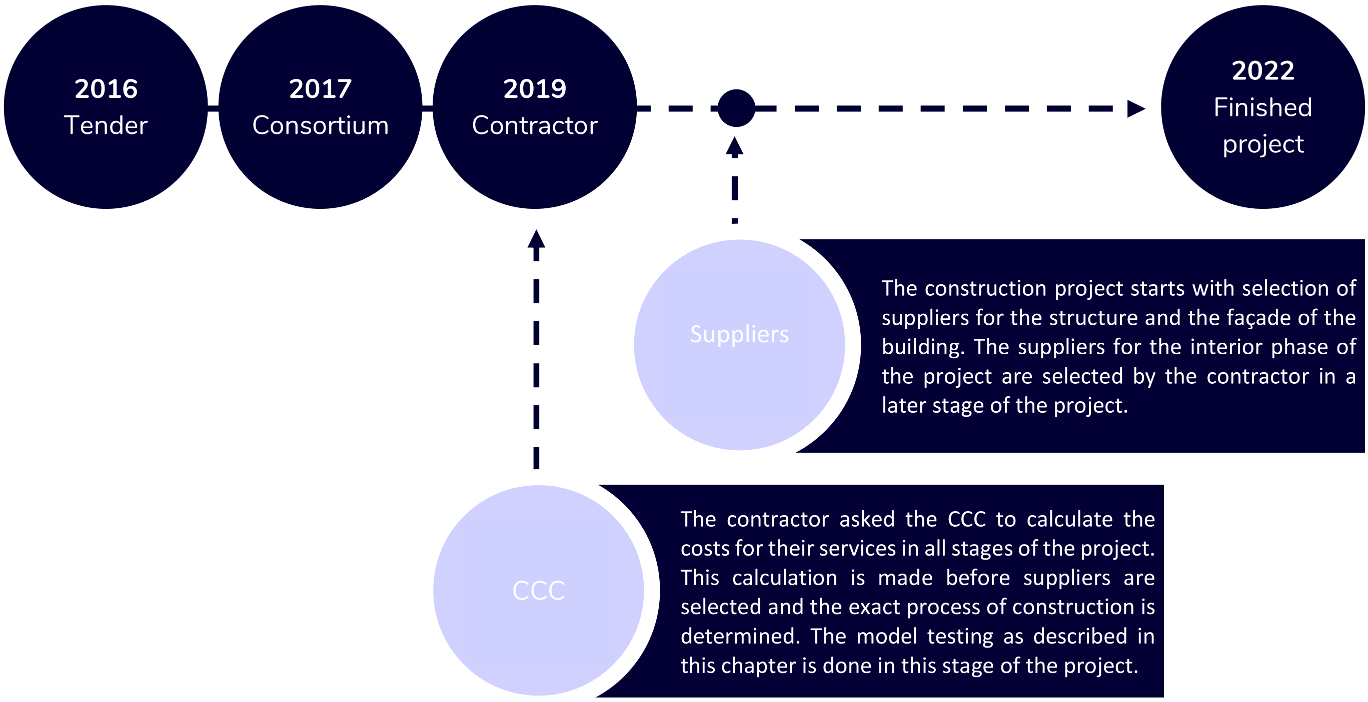

Figure 37 Planning Wonderwoods project to highlight current stage of the project.

6 MODEL TESTING 3. MODEL INPUT

The model as developed in this research is tested in a real case. Data is collected in an early stage of the Wonderwoods project. Collecting the information in the project to test the model highlighted that some aspects of the model could not be tested due to missing model input. The first aspect is the project-related data. The level of detail required by the model could not yet be provided by the contractor, because the process of collecting this data had not yet started. The second aspect is the standard costs figures, these are available for many materials and processes, however, are not adjusted for the exact configuration of the project. It requires specialisation to convert these standardised costs to project-specific costs. The last aspect is experience-based data. This is data on the performance of the CCC and is measured in previous research and is only generalizable for a few aspects. A summary of the available model input is provided in Table 3. An extensive description of the available information is included in appendix I.

Activity	Aspect	Project-related input data	Generic cost data	Experience-based data
Transport	Distance	Locations of suppliers are not yet known	-	Sector average distances and project distances measured in previous research
	Mode of transport	Not yet known	Fixed load capacity Average speed Rental price	Load factor based on previous research and sector averages
Loading	Trucks standing still	-	Rental price	Project averages from previous research
Waiting	Trucks standing still	-	Rental price	Project averages from previous research
Costs at CCC	Handling	Material quantity	Labour costs Equipment costs	Fixed prices of CCC Utrecht
	Storage	Material quantity	Rental price location Costs for facility	Fixed prices of CCC Utrecht
	Consolidation	The materials that need to be combined is not known yet	Labour costs Equipment costs	Experience data is limited. Previous research measured the process for a few materials but not for all. The specific characteristics make it hard to generalize the available data.
On-site	Unloading	Material quantity	A database with generic cost data can be used as a traditional benchmark. Bouwkostenonline is one example.	The comparison with traditional process is researched for one supplier. These results are used for the model development, however, are not generalizable for the WW case.
	Transport	The site layout is not known yet		
	Fixing	Planning is not known yet		

Table 3 Summary of available model input in Wonderwoods case.

In the previous paragraph is explained how the input for the model is developed based on previous research and experience from projects. Input that is missing in the preparation stage of the project is replaced by estimations or averages if possible. Figure 38 shows the part of the model dashboard for the supplier of tiles that could be tested in the Wonderwoods case. Included in the tests model are the costs for transport (1 2 3), loading (4 5 6), waiting (7 8 9), handling at the CCC (10), and storage at the CCC (11).

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The model is used to calculate the costs and savings in the process to predict the impact of implementing the CCC Utrecht in the Wonderwoods project. The number of assumptions makes it impossible to predict the exact impact of the implementation of the CCC with the tested model. The model, however, can be used to provide insight during the preparation stage of the project for multiple scenarios. These scenarios are created by varying in the following factors, the load factor, distance from the supplier to the CCC and the site, quantity of load carriers as a result of multiple materials suppliers, and storage length at the CCC. A fragment of the calculations for scenario one for the supplier of tiles is seen in Figure 39 on page 58. An overview of all calculations is included in appendix K.

In the calculations of the scenarios, the materials for tiles and aerated concrete are isolated from the total quantity of materials in the Wonderwood. Both suppliers are not selected by the main contractor yet and materials could potentially be bought directly from the factory or via a subcontractor that also provides labour. Therefor average distances of 40, 90, 120, and 150 km are used to calculate transportation costs.

The load factors vary for three different scenarios. In all scenarios, the traditional load factor of 40% is kept equal but the load factors for transport in the situation with CCC differ.

Scenario one is the ideal situation in which transport is coordinated by the operator of the CCC. The supplier delivers with 90% load factor to the CCC and the CCC delivers with 90% load factor to the construction site.

Scenario two is a less optimal situation. A mix of suppliers and smaller quantities together perform with a lower average load factor of 75% to the CCC. The CCC operator can still consolidate optimally and deliver from the CCC to the construction site with a 90% load factor.

The third scenario is a situation without coordination of the CCC operator. Suppliers deliver to the CCC and organised their own supply stream as occurred in a specific part of the supply at the Noordgebouw case (De Bes et al., 2018). In this scenario, the load factor for transport by suppliers to the CCC and from the CCC to the site is 75%.

The handling costs at the CCC have a fixed price for each load carrier and do only vary due to the number of materials. The costs for buffer storage at the CCC are calculated with a price per day. To show the impact a storage period of two and three weeks is calculated for al scenarios to show the overall profitability of implementing the CCC in the process for the Wonderwoods case.

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Figure 39 Model results for the process of the supplier off tiles with 40% load factor traditional and 90% in the situation with CCC.

The savings for al combinations of variables calculated in the Wonderwoods project (see appendix K) are summarized in Table 4. The provided overview shows the impact on the total construction costs of implementation of a CCC in comparison to the traditional process. Due to the limited input the model could only provide results for the transport, waiting, loading, handling and storage costs at the CCC.

Transport distance

The results show the impact of transport distance on the savings resulting from implementing the CCC Utrecht in the Wonderwoods case. A higher transport distance results in higher total costs for transport but the savings resulting from implementing the CCC increase as well. Previous research showed that the sector is not aware of the expected transport distance in the preparation stage of the project (De Bes et al., 2018) and arguably in the total project. This is also the situation in the preparation stage of the Wonderwoods project. Previous research measured the average distance of transport for the Voortzetgebouw project at 134 km and the Noordgebouw at 109 km(De Bes et al., 2018). This is above the sector average of 75 km because the Voortzetgebouw project had a large supplier in Germany and the Noorgebouw project worked with numerous suppliers from the area of their office in the area of Hengelo (De Bes et al., 2018).

Load factor

The results illustrate that the load factor of the supplier to the CCC has the highest impact on the savings in the project. High quantities of materials, however, make it possible for the suppliers to deliver with high load factors to the CCC.

Storage

Storage costs at the CCC are treated as extra costs in the process because there is no data for the storage on-site or at the supplier's yard. The results show the incentive for the contractor to minimize the buffer storage at the CCC from three weeks to two weeks by organising the fixing process efficiently.

As can be seen in Table 4 implementing the CCC is profitable for the sector average distance if the storage process is minimized and the load factors are optimized by coordination of the process.

Table 4 Calculation results overview (net savings in euros [€]).

The model that is developed and tested in this research includes activities that are tested on three different levels. The final framework of the model as developed in this research can be seen in Figure 40 on the next page.

The first level of the model contains all activities that are part of the logistical process as explained in the literature. These aspects could potentially be influenced by the implementation of a CCC; however, the aspects are not tested in previous research. These aspects include the costs related to the procurement activities, the process management activities (such as changing delivery schedules) and the costs for stocking at the suppliers' yard or at intermediate warehousing. The impact of implementing a CCC in the process on the costs related to these aspects could be a topic for future research.

The second level of model elements includes the activities that are measured in previous research on the impact of including a CCC in the logistical process related to construction. These aspects are marked with a light circle with a number in Figure 40 on the next page and are included in the model described in chapter 5. These aspects are the Consolidation into work packages at the CCC, the unloading activities on-site, the transportation on-site and the fixing process. The steps in the model could be practically tested with the data generated in previous research and available documents provided by the CCC Utrecht. All these elements could be part of the model when the required input data becomes available. Generating more experience data for these aspects by measuring the duration of the activities could improve the capacity of the model to predict in the impact of implementing a CCC on the costs of a construction project in more detail.

The last level of model elements includes the activities that are described in the literature and could be tested practically and in the Wonderwoods case. These aspects are marked with a dark circle with a number in Figure 40 on the next page. These activities include transportation, waiting time, loading time, handling at the CCC, and storage at the CCC. In the Wonderwoods case, the factors are calculated with sector averages and for multiple scenarios. When the specific project data becomes available in more detail the model can be used to predict the impact of including a CCC on the logistical costs of the construction project to a higher degree of certainty.

6. FRAMEWORK III

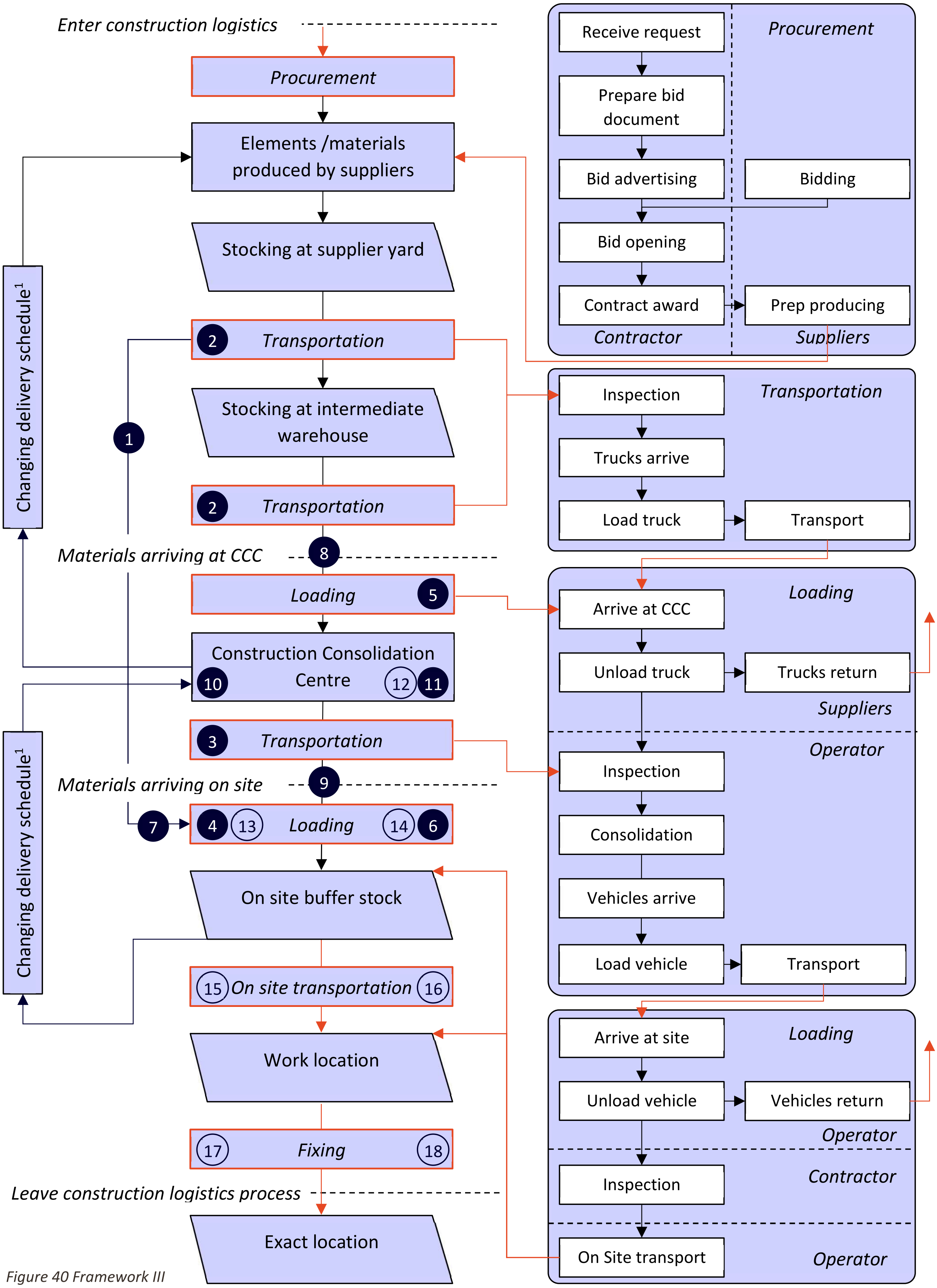

Figure 40 Framework III

To validate the process in which the calculation model is developed an analysis of all decisions is made. A technical overview of all decisions and input on which decisions are made is included in appendix M. The calculation model is the result of a continuous process including multiple iterations. The initial model is developed with the knowledge described in the literature. This initial model is further developed with employees of the operator of CCC Utrecht and multiple documents provided by the operator. The input of the experts resulted in a more pragmatical approach to modelling and a new calculation model. The new model is extended with the factors measured in previous projects of the CCC Utrecht that where measured and described in various reports of students and TNO. This complete and functioning model was tested in an action research setting in the Wonderwoods project which resulted in various decisions to enable insightful results for involved stakeholders. A number of modelling decisions are made during the development of the model.

1 > *Reduction in stakeholders*

The initial model required (financial) information that is scattered across the entire supply chain of the construction project. Measuring all activities during the project or creating an ideal case as was done in the paper of Yuan Fang and Thomas Ng (2011) proved to be challenging in the process of developing the model. Knowledge of processes is scattered across stakeholders and can differ for each project and between the type of materials that are supplied and are therefore difficult to copy from a previous project. Information regarding the CCC itself is knowledge of the operator and is measured in previous research and is available for the development of a calculation model. The quality level of information is based on past projects and is limited due to the innovative character of the CCC in processes. Information regarding the project is in the possession of the main contractor. The project related data consists of the number of materials, technical specifications, the geometry of the building, and planning. The quality level of this information depends on the planning of the contractor and the activities that are conducted by the employees of the contractor in the preparation stage of a project.

2 > *Reduction in costs factor complexity*

The initial model had a costs structure for all activities divided into costs for labour, equipment, material and capital. The first iterations of the model with information available in the past cases resulted in a new approach to the costs factors. The costs related to transport are reduced to a rental price per hour. The number of journeys can be influenced by the implementation of the CCC. The rental price, however, will stay the same and could, therefore, be calculated with the fixed price. The costs structure related to storage at the CCC was split by the operator of the CCC in handling costs and storage costs. Handling costs include the labour and equipment costs and have a fixed price the storage costs are calculated with a fixed rental price. Since the model is developed for implementation in practice the decision to adopt this approach in the model is acceptable.

3 > *Limited to activities measured in previous research*

All activities included in the final model are factors that are measured in previous research. In the modelling process for the activities the outcome of the model could be compared and tested with the results of previous research to check the reliability of the model. The activities that are not measured in previous research are excluded from the model and are included in the recommendations for future research.

The developed model is validated in practice by the means of an expert review. A digital survey amongst all experts involved in the Wonderwoods project is used. Respondents are asked to rate in the way they agree to the statements on a scale from 1 totally agree till 5 totally disagree in the first question and to explain their rating in a second question.

Approach

The prepared statements consist of two categories. Five statements are related to the model developed in this research and the aspects included in the model. These statements are part of the validation and are listed below.

Statement 1: The model developed in this research provides a clear insight into the possible savings on costs related to transport, waiting and loading times.

Statement 2: The model developed in this research provides a clear insight into the costs related to buffer storage and handling at the CCC Utrecht.

Statement 3: Using the average distance for all suppliers in the preparation stage of the project is for cost accounting is enough.

Statement 4: Quantities of materials for the fixing stage of the project are in the preparation stage of the project entirely known.

Statement 5: Quantities of materials for the fixing stage of the project can be converted to quantities of load carriers in the preparation stage of the project.

Respondents

The respondents in the survey employees of:
Main contractor: 2, Coordinator Construction Logistics and Trainee
CCC operator: 2, Coordinator construction logistics and Financial Controller

Results

Statement 1: The model developed in this research provides a clear insight into the possible savings on costs related to transport, waiting and loading times.

Three out of four respondents agree with the insight provided by the model. A note made by one of the respondents is that; the model is never finished. The savings in the process are described as subjective. Measuring the actual savings during the project will be necessary to communicate the savings with the suppliers and sub-contractors.

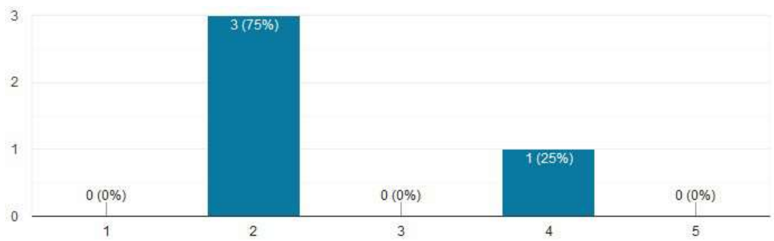

Figure 41 Results statement 1

Statement 2: The model developed in this research provides a clear insight into the costs related to buffer storage and handling at the CCC Utrecht.

Three out of four respondents (totally) agree or with the statement. They mention that the fixed prices for storage and handling provide a clear overview of the costs. The costs, however, do differ between CCCs. The costs overview should be communicated in the same manner to make them comparable.

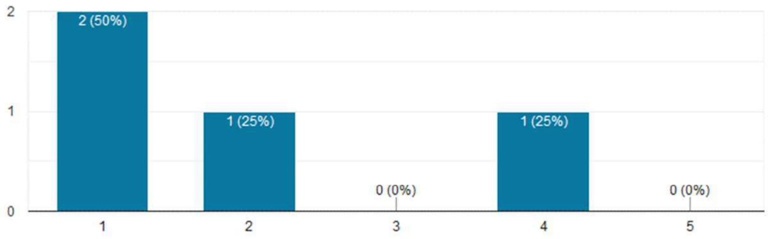

Figure 42 Results statement 2

Statement 3: Using the average distance for all suppliers in the preparation stage of the project is for cost accounting is enough.

The respondents all agreed or disagreed in different manners. One mentions that the averages are enough information for this stage of the project another mentions that the figures are good enough in this stage of the project, however, they should be calculated more precise by using the zip codes of suppliers.

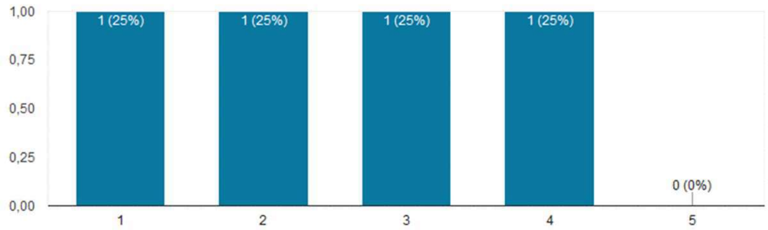

Figure 43 Results statement 3

Statement 4: Quantities of materials for the fixing stage of the project are in the preparation stage of the project entirely known.

Two of the respondents mention that the quantities are highly depending on the information provided by the contractor. Another mentions that in the current stage of the Wonderwoods project not all information is available yet. Choices made by the client are a reason for this and in following stages changes in the plan and choices made by the buyers of the apartments could have an impact on the data.

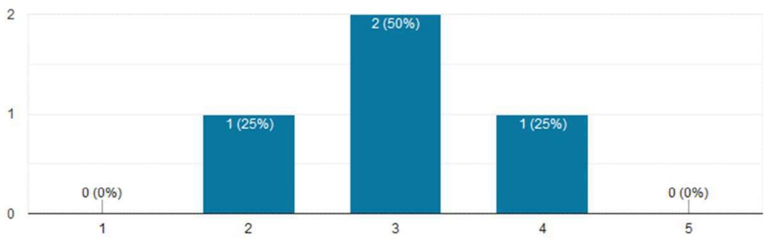

Figure 44 Results statement 4

Statement 5: Quantities of materials for the fixing stage of the project can be converted to quantities of load carriers in the preparation stage of the project.

Two of the respondents replied with neutral and two respondents disagree with the statement. The respondents mention that this information is owned by the contractor. No information by suppliers is mentioned as a reason that it cannot be converted. One respondent mentions that it will depend on the demand if there will be supplied in full load carriers with materials. If demand is lower and smaller packages are needed this will result in extra load carriers.

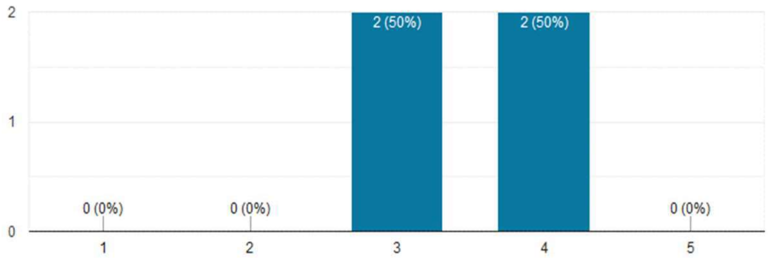

Figure 45 Results statement 5

RESULTS

Part V

The second part of the survey that is described in the previous paragraph is used to discuss the developed and tested model. Five statements are related to aspects that are mentioned in the literature and included in the developed model but due to reasons explained in the previous chapters are not part of the model tested in the case study. These statements and the reactions are listed below.

Statement 6: Costs related to consolidation into day production packages at the CCC need to be known in the preparation stage of the project.

Three of the respondents agree with the statement and mention that it should be available. One mentions that a rough estimation would help that could be optimized during the next stages of the project. Two mentioned that the available data is a reason that this is still not possible.

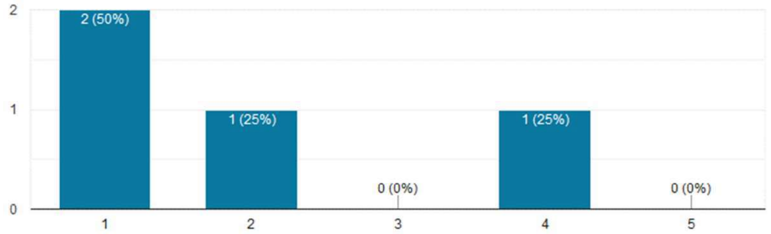

Figure 46 Results statement 6

Statement 7: Costs related to on-site transport with runners need to be known in the preparation stage of the project.

Three respondents (totally) agree and one reacted with neutral. Two respondents mention that it should be available, but that extra data and experience are needed to be able to calculate this. One respondent mentions that it depends on the progress of the project. The number of runners needed depends on the progress.

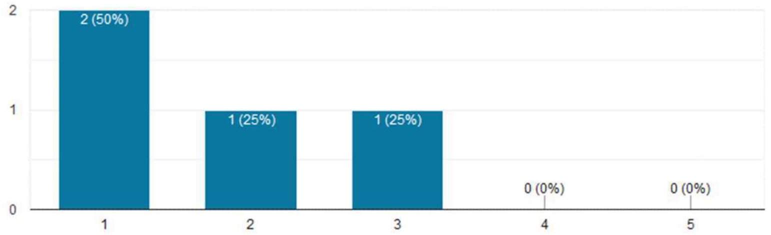

Figure 47 Results statement 7

Statement 8: Savings on the process of suppliers/sub-contractors by increase labour productivity on-site need to be known in the preparation stage of the project.

Two respondents agree that the information should be available. One respondent mentions that extra data is needed to calculate the savings for all involved stakeholders. One respondent mentions that it could be in favour of the sub-contractors but would not be necessary for the main contractor in this case. One respondent agrees that it should be known but is convince that this new process is more expensive than the traditional process.

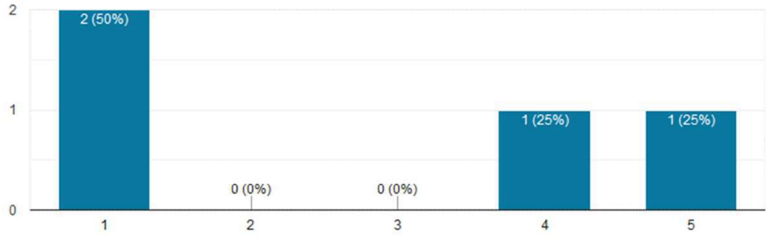

Figure 48 Results statement 8

Statement 9: Incidental savings (for example saving of large quantities of materials because of less damage) as a result of the implementation of the CCC cannot be included in the model but would be important in the decision of including a CCC in the project.

Respondents reacted divided on this statement. One mentions that providing insight into the costs of failure can create a reduction in these costs. It should not be the most important reason for using a CCC. It should be a part of the motivation because the real savings are made in other aspects. One respondent mentions that it could impact the choice of using a CCC. One respondent mentions that these incidental savings will not result in actual savings and that they differ highly between projects, as a result of personnel on-site.

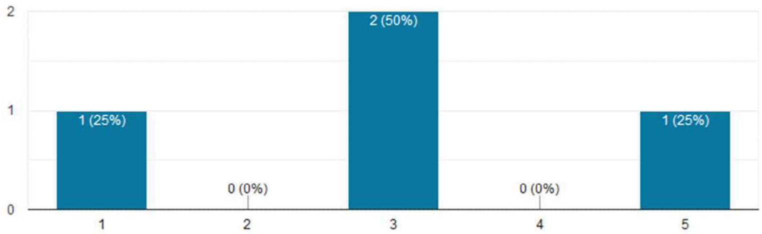

Figure 49 Results statement 9

Statement 10: I missed an aspect in the model that would add value in my opinion.

One respondent mentioned that the model needs a clear output for the client with the total costs of every element. One respondent mentioned that the costs of transport and consolidation of the structure and façade of the building should be included in the model as they could provide more insight into the effect of the CCC. One respondent mentions that the model should include more data related to traffic information for the urban areas and areas of congestion. Also, for the roads towards the CCC.

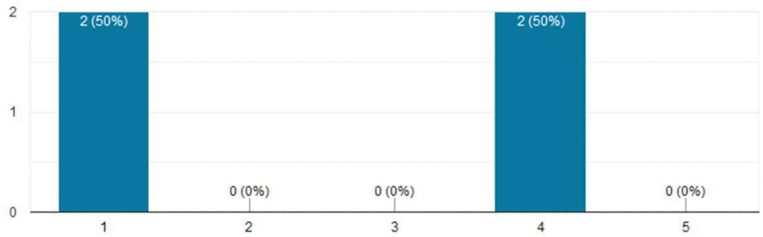

Figure 50 Results statement 10

This paragraph provides an overview of the elements of this research that require discussion and the limitations within this research. The paragraph is divided over two topics being the developed model and the research scope and process.

Discussion and limitation of the model

The model developed in this research compares the difference between the traditional process and the new process including the CCC. Expected savings are based on data collected from different comparable projects and previous research. The input for these factors could, however, be discussed.

- **Savings on transport** - The savings on transport are an important factor for the profitability of including the CCC in the process. Based on average load factors in the construction industry measured in previous research it is assumed that suppliers in the traditional process deliver to the construction site with 40%. It could be possible that the suppliers for a specific project are able to optimize the transport to site and increase the load factor. The average distance is calculated for multiple distances including the sector average of 75km. The journeys are calculated with a single type of truck with a specific maximum capacity. When the level of detail in the information increases however and the process for a specific supplier becomes available. It could occur that all aspects are more optimistic and the savings by changing the process diminish. All these factors could potentially be influenced by the main contractor. If suppliers are sourced locally the transport distances become so low that savings can not cover the costs. Previous projects, however, showed that sourcing is project-specific and depends on the type of materials used and the available suppliers for these materials. The high influence of the process and the project-specific situation could be an argument for postponing the modelling process of the CCC until this level of detail in the process is reached.

- **Traffic** - The duration of the journeys in the model is calculated with an average speed on the highway and average speed in the inner city. In reality, trucks deal with increased traffic in peak hours. One of the advantages of the CCC is that suppliers are free to deliver in off-hours and are able to avoid peak hours. This could potentially lead to higher savings on transport costs than the developed model calculates. This factor is mentioned by one of the experts in the conducted expert survey. Including this factor could increase the exactness of the model output.

- **Storage costs at CCC** - The buffer storage costs at the CCC are calculated with a standardised period of two and three weeks. This factor can be influenced by the project and the approach to the construction process. If the day production of the project is so high that the material deliveries to the CCC with full freights and the deliveries of the CCC with full freights to the construction site are only a few days apart from the storage capacity and time needed at the CCC will be lower.

- **Costs related to storage** - Buffer storage and handling at the CCC in this research are calculated with the cost estimations of CCC Utrecht. In the current model, this storage is added as a costs factor to the process. However, the storage capacity of the CCC could potentially lead to a decrease in capacity needed at the supplier's yard or intermediate warehousing. This could generate potential extra savings for the suppliers of the materials.

- **Benchmarking** - The developed model compares the traditional approach to construction logistics with the process including the CCC. This is a snapshot of the project at a certain moment in time. Changes to the type of materials or the process during the execution of the project could diminish the effects calculated in the preparation stage of the project. This needs to be considered when changes are made during the execution of the project.

Discussion and limitations of the research

The distribution of construction logistics costs is based on the contractual agreements amongst the owner, main contractor and suppliers. However, the total costs of the project will be transferred to the owner who needs to pay for the project in the end. Therefore this study adopted the perspective of Yuan Fang and Thomas Ng (2011) to consider the construction logistics costs from the owner's viewpoint. During the research, the perspective on this matter changed. In the process including the CCC, the main contractor is the client of the CCC and therefor the stakeholder to convince of the savings in the process.

The model developed in this research is for the projects that are tendered based on Design-bid-built. This is currently the most used contract in the Dutch construction sector and is a process with a finished design before contractors are selected. A finished design limits the variables in the initial model for comparing the construction logistics costs when implementing or not implementing a CCC. Insight from this study could potentially lead to design input in new projects, due to time limitations this process is excluded from the scope of this research.

The conducted literature research resulted in an extensive list of activities and cost factors included in the construction logistics process. A number of activities could not be tested with results from previous research and are therefore excluded from the model despite the fact that they could potentially be impacted. These factors are therefore included in the recommendations for future research. Other activities could be tested with the results from previous research but due to missing project related information could not be tested in the conducted case study. In the survey amongst experts is mentioned by multiple experts that these factors should be included in the model and that the data should be made available in the project.

A barrier for the implementation of CCCs in construction projects as discussed in the introduction is the lack of financial models that measure the impact on efficiency and costs for the involved parties. Therefore, this research is focussed on the development of a financial model from a business economics perspective. Actual costs (savings) that are part of the construction process are included in the model. The transparency of these costs could convince private parties to implement the innovations in their processes. The implementation of these innovations could, however, have financial benefits for society as a consequence off ecological benefits, reductions of traffic in inner cities etc. Transparency of these costs (savings) could lead to the involvement of public parties. These public costs (savings) are not included in the developed model because they do not influence the current supply chain.

The research question answered in this paragraph is: *Which definitions and aspects of construction logistics need to be included in the model?*

Costs related to transport

Transport costs from the supplier of materials to the construction site is the first aspect that is included in the newly developed model. In a traditional project, this includes direct transport from the supplier to the construction site organised by the supplier or a logistical company that works for the supplier. In the process with a CCC, the supplier organises the transport to the CCC coordinated by the operator and the transport to the site is organised and coordinated by the operator of the CCC. This enables higher load factors for transport from 40% in the traditional process up to 90% in the process including the CCC. Suppliers can deliver to the CCC with full trucks of materials that can be stored in the buffer storage before being transported to site and are therefore not dependent on the exact working schedule on-site and limited storage space on-site. The operator of the CCC can combine transport of multiple materials to ensure this higher load factor in transport to a site that is aligned with the exact working schedule and limited space of on-site storage.

Costs related to loading of trucks

The second aspect included in the model is the costs related to the time that trucks are loaded and unloaded in the process. In the traditional process, trucks are loaded at the supplier's storage location and unloaded at the construction site. In the process with the CCC, the loading process at the supplier's storage is the same. Extra time is added to the process by unloading and loading at the CCC for all journeys in the new situation. Unloading at the construction site is done by a specialized team of runners which increases the speed.

Costs related to waiting by trucks

The time trucks need to wait before unloading can start is the third aspect included in the model. In the traditional process, trucks need to wait for the availability of cranes, personnel on-site and a location to unload. Due to increased coordination and unloading in off-hours (when construction is finished) the waiting time in the new process decreases.

Costs related to handling at the CCC

A new aspect in the construction logistics process as a result of the implementation of the CCC is the handling at the CCC. This includes the labour and equipment costs related to unloading and loading trucks at the CCC. These costs are calculated for all load carriers with a fixed price.

Costs related to storage at the CCC

These costs result from the space used in the new process for buffer storage. The costs are based on the rental price for storage space at the CCC. The rental price is a result of the costs for the quality of the storage facility.

Costs related to consolidation at the CCC

Including the production of workday packages to the activities of the CCC increases the costs at the CCC. These costs are related to staff and equipment used to combine materials on new load carriers. The costs are dependent on the quantity and the number of different materials that need to be combined.

Costs related to unloading at the construction site

The costs related to labour on-site for the staff that unloads the trucks differs between the traditional process and the process including the CCC. This process is conducted by personnel of the supplier in the traditional process while in the new process it is conducted by a team of runners.

Costs for on-site transportation

The costs for on-site logistics are related to the crew that is unloading the truck and the crew that is putting the materials on the work location. In the traditional situation, this is done by the employees of the labour supplier (for example a tiler) reducing their production time. In the process including the CCC, this process is coordinated by the operator of the CCC and the on-site logistics are executed by runners. These runners can be the employees who clean the construction site during the day and do not need the same level of skill as for example tilers.

Costs for fixing on-site

The costs related to fixing the materials in the final place are the same in the traditional process and the process that includes the CCC. The production capacity, however, increases because specialized personal does not need to work on the unloading of trucks.

2. MODEL INPUT

The research question answered in this paragraph is: *Which information should be available in the preparation stage of the project to provide input for the model and which generic cost data can be used?*

The information that should be available in the preparation stage of the project consists of three categories. These categories are project-related input data, experience-based data, and generic cost data.

Project-related input data

The project-related input data consists of the data related to the characteristics of the building, the construction site, the process, and the planning of the project. The project-related input data that is required for the calculations consists of:

- Material quantities - The quantities should be available in production units divided in day production capacity and in the number of load carriers with the size of the load carriers. This data is necessary for the calculations of transport, handling at the CCC, storage at the CCC, consolidation, unloading, on-site transport, and fixing.

- Locations - The production or storage locations of the suppliers, the CCC and the construction site need to be known. This data is necessary for the calculations of transport.

- Modes of transport - The type of trucks that are used in the logistical process needs to be known. This data is necessary for the calculations of transport, loading and waiting.

- Planning of the fixing stage - The planning and work orders are required to plan what supply streams can be combined in consolidation, to estimate the required capacity in buffer storage, and to calculate capacity and time spend for on-site transport.

Experience-based data

The data related to the experience with the implementation of the CCC is collected in previous research. This data includes the activities and costs related to the activities conducted in the new process by the staff of the CCC.

- Activities of the CCC - The time required for the loading and unloading of trucks at the CCC, for the consolidation into work packages in diverse configurations, for the unloading and the on-site transportation of materials needs to be known and generalizable for all types of projects.

Generic cost data

The generic cost data required for the model includes the cost of labour and equipment in the construction sector. Benchmarking with the traditional process requires data on the activities and cost related to the activities. These activities include the activities on-site conducted by the supplier. The processes including the costs are available in generic cost databases.

- Labour cost - The employees of the CCC, the specialised personnel of the subcontractors and the runners specialised in un-loading and on-site transport are all skilled at different levels with different wages.

- Production speed - The activities as part of the fixing process for a specific material and the costs related to these activities are included in data sources for standard cost figures. These data sources can be used to calculate the cost for the traditional process with the model as a benchmark for the process including the CCC.

- Equipment cost - The rent prices of trucks and the specifications of trucks in terms of load capacity and average speed are required to model the transport cost of the project.

3. MODELLING & OUTPUT

The first research question answered in this paragraph is: *How to accurately model and predict the financial impact of using a Construction Consolidation Centre in a new costing model?*

This research showed that accurately modelling the financial impact starts with an understanding of the activities that are influenced by the implementation of the CCC. The activities for both the traditional process and the process including the CCC are analysed and included in the framework to enable benchmarking.

The developed framework with the activities included in the process could thereafter be filled with input data. The input data for the model as described in the previous paragraph consists of project-related input data, experience-based data for the process including the CCC, and generic cost data on the traditional process and costs related to labour and equipment.

The model can be used to predict the financial impact of the implementation of the CCC on the activities included in the model for the process with a high level of certainty when the required model input is available. The required project-related input data is dependent on the level of preparation conducted in the process. Before the model can be used to predict the financial impact this level of detail needs to be known for the project.

Implementing the model in an earlier stage of the project is still possible when the selection process of suppliers has not yet started, and project-related input data is only available on a general level. In this situation, the model can be used to provide some insights about the potential impact of the implementation of a CCC. This approach is based on sector averages for transport distances, average load factors, standardised modes of transport and rough estimations of the material quantities and time consumed in activities. With these estimations' insight into the savings on transport, waiting, loading and the costs at the CCC can be provided to the main contractor for multiple scenarios.

The second research question answered in this paragraph is: *What Output should be generated by the model to create added value in the preparation stage of the project?*

The developed model should enable for benchmarking between the traditional process and the process including the CCC. To enable benchmarking the developed model should provide clear insights as the costs related to transporting (travelling, waiting, loading), cost at the CCC (handling, storage, and consolidation into work packages), and cost at the construction site (unloading, transport and fixing).

The logistical costs related to construction are defined in this research as the costs related to transporting (travelling, waiting, loading), cost at the CCC (handling, storage, and consolidation into work packages), and cost at the construction site (unloading, transport and fixing).

The experts that responded to de survey underline that savings for on-site transport and the costs for runners should be generated by the model in the preparation stage of the project as well. The costs for the production of work packages is also seen as a necessary output of the model. This process, however, requires more data and experts mention this in their response. One of the respondents suggested that the stages for structure and façade should also be included as model output.

4. MODEL IMPLEMENTATION

The research question answered in this paragraph is: *Which conditional factors determine the implementation of the model?*

The implementation of the model in the construction project requires a couple of conditions. This list is a result of the observations during the work sessions with the project team of Wonderwoods and the results of the conducted survey. The factors are connected to research conducted by (Blayse & Manley, 2004) on the factors that influence the implementation of innovations in the construction industry. Since no structured format is used to collect the factors this list is by no means exhaustive.

Data

The first factor is the available information. Currently, the model is tested with averages and estimations and data measured by TNO in a couple of projects. To predict the exact impact a larger database is necessary. Data that is verified with the suppliers will increase the change that the outcomes of the model will be accepted by all stakeholders involved. Only when the output is accepted the model can be used to create a new division of savings resulting from the implantation of a Construction Consolidation Centre. This aspect is mentioned in work by (Blayse & Manley, 2004) as building up organisational resources.

Project team

The project team and its members can also have an impact on the implementation of the model. Believing in the innovations in the first place and willing to invest time and energy is key to a successful implementation. In the Wonderwoods project, this energy is shared by the managers of the contractor and the operator of the CCC. The case of project Voortzetgebouw showed that changes in the project team can result in a lower performance of the innovations (De Bes et al., 2018).

Transparency

The Wonderwoods project was unique in the sense that the companies involved where all part of a larger holding. This made the transparency of financial information between stakeholder easier because it can be seen as internal information. The implementation of the model, however, requires this level of transparency since the costs and savings are scattered over multiple stakeholders. This conditional factor is described by (Blayse & Manley, 2004) as mobilising integrated approaches to construction projects as a response to the fragmentation of the industry.

Time

Implementation of innovations like the CCC requires time. The operator of the CCC needed to invest time in collecting information for converting quantities of materials provided by the contractor to quantities of transport. This preparation time before calculations can be made is likely to increase if the input data for the model increases in the level of detail. Developing standardised frameworks for information sharing in these innovative processes can help with limiting the time increase. This aspect is described by (Blayse & Manley, 2004) as improving knowledge flows.

5. RESEARCH QUESTION

The answers to the research questions described in the previous paragraphs result in an answer to the main research question:

> To what extent can the logistical costs related to construction be modelled in the preparation stage of a project to predict the impact of the implementation of a Construction Consolidation Centre?

The logistical costs related to construction are defined in this research as the costs related to transporting (travelling, waiting, loading), cost at the CCC (handling, storage, and consolidation into work packages), and cost at the construction site (unloading, transport and fixing).

All the cost factors are included in the model developed in this research and are tested with either past case data, or with past case data and the data provided by the contractor of the Wonderwoods project. The model can be used to calculate the logistical costs related to construction to predict the impact of the implementation of a CCC on the project to a large extent. The calculations, however, require experience-based data for the activities of the CCC, generic cost data for aspects like rental prices and labour costs, and project-related input data. The extent to which the model can predict the logistical costs related to construction depends on the level of detail of the provided data. This data should be available at a certain moment in the preparation stage of the construction project.

Implementing the model in an earlier stage of the project is still possible when the selection process of suppliers has not yet started, and project-related input data is only available on a general level. In this situation, the model can be used to provide some insights about the potential impact of the implementation of a CCC. This approach is based on sector averages for transport distances, average load factors, standardised modes of transport and rough estimations of the material quantities and time consumed in activities. With these estimations' insight into the savings on transport, waiting, loading and the costs at the CCC can be provided to the main contractor for multiple scenarios.

6. RELEVANCE

Scientific

One of the purposes of this research was to contribute to bridging the gap in the literature as discussed in the introduction of this report. This is done by three steps in the development of the model, the activities included in the process are analysed, the included activities are combined in a new model that enables benchmarking, and the developed model is validated with experts in a real construction project.

The scientific relevance of the conducted research is two-folded. The developed model is a new step towards a calculation model that can predict the impact of implementing a Construction Consolidation Centre in the supply chain of a construction project in the Dutch construction sector. With this result, it contributes to bridging the gap between measuring successful experiments as was done by (De Bes et al., 2018) and actual implementation of the new methods. De Bes et al. (2018) stressed the need for a model that provides insight into the cost-effectiveness of innovative solutions. The developed model contributes to these insights and provides a conversation starter for a new division of revenues within the supply chain.

A second contribution of the conducted research is to the field of activity-based costing as described in the paper of Yuan Fang and Thomas Ng (2011). They stressed the need to test their framework for analysing construction logistics with experts from contractors and suppliers in a real estate project. This research proved that a selection of the developed framework could indeed contribute to tracing back the consuming activities. The framework contributed to predicting the impact of implementing new activities like the construction consolidation centre to the construction process. Tracing the consumption back to a cost element, however, proved to be difficult in the early phase of the preparation stage of construction projects analysed in this research. Validation of the developed model with the experts involved in the construction project increased the understanding of the applicability of this method for cost accounting in this early stage of the project.

Social

The social relevance of implementing innovations like the CCC as explained in the introduction of the report is evident. Proving the exact relationship between this research and increased implementation of CCCs is difficult. The developed model and the results of implementing the CCC in this research, however, illustrate the impact that could be made. The reduction in transport to the construction site will lower the impact the construction sector has on the environment and the cities. Which by itself should be an extra motivation for professionals working in the construction industry to at least consider implementing these innovations in future projects.

Practical

The logistical costs related to implementing the CCC in the previous projects were done by a fixed price and measuring during the process. Insight into the actual costs occurred was created during or even after the project was finished. The developed model provides a tool for the operator of the CCC to create insight into the impact of the CCC on the costs of the construction process in the preparation stage of the project. If future research on-site would be conducted the actual occurring costs could be measured and the output of the model could be verified. The developed model could then provide a conversation starter for the main contractor in the negotiation with suppliers of materials and labour. This could be the first step of a new division of the savings made by the implementation of the CCC eventually contributing to increased implementation of these innovations.

1. RESEARCH

This paragraph provides an overview of the recommendations for future research resulting from the conducted research.

The model developed in this research is created with literature and input from the CCC Utrecht and is tested in the Wonderwoods project. Using the developed model as a starting point for new research and testing it in other projects could help to increase the reliability of the predictions that can be made with the model.

Missing activities

In this research, a couple of activities included in the initial model could not be tested with results from previous research. These activities are the procurement, process management, stocking at the supplier’s yard, and stocking at intermediate warehouses. The impact of implementing a CCC in the construction process on these activities has not been measured in previous research. A focus on measuring these aspects could help with better understanding the impact that including a CCC in the project has on the total costs of a construction project.

Increasing the database

The aspects included in the model are tested with results of previous research on the impact a CCC has on activities in the logistical process. The amount of experience-based data about the activities included in the model is still rather limited. Data on activities related to consolidation, and activities on-site lacked generalizability. A larger database with experience-based data on the processes including a CCC will enable the further development of models and will contribute to proving the impact of innovations in construction logistics. Measuring these aspects in more detail related to the project-specific characteristics can help with the adjustability of the data for different types of projects.

Missing cost categories

In this research, the costs category of capital, including opportunity cost frozen in inventory as explained in literature is not included in the developed and tested model. Analysing the process and tracing back these costs to the cost owner could highlight another aspect that is impacted by the implementation of the CCC. A faster construction process could potentially lower these costs.

Factors for implementation

In this research, the factors that can impact the implementation of the model could only be tested by observations in limited time for only one project. Analysing the project organisation and its members and their influence on the implementation could help with a better understanding of the factors that influence the implementation of both the model and the CCC. Conducting this type of research could also help with a better understanding of the output that should be generated by the model to convince the involved project members.

Smart solutions for personnel

This research is focussed on the activities included in the delivery of materials to the construction site. The CCC also enables an alternative for the process by which the construction workers get to the construction site. In future research, the possibilities of including these activities and alternatives like a shuttle service in the model could be tested.

Combining supply with waste collection

The scope of this research is predicting the impact a CCC could have on the supply of materials to the construction site. The logistical challenge of the waste collection on-site and the transportation of waste from the construction site to the waste processing companies, however, could be combined with the process of supply. Analysing the traditional process of waste collection on construction sites could enable benchmarking with the alternative solution that includes the CCC. This opportunity for CCC is also mentioned in the book of (Sullivan et al., 2010).

Monitoring the Wonderwoods project

A final recommendation would be to monitor the Wonderwoods project during the construction. Measuring the actual transports distances, waiting times, loading times, load factors, consolidation times and costs and on-site transportation could be beneficial for benchmarking the predictions made with the current model and could help to improve the current model to one that can be used in other projects as well.

10 RECOMMENDATIONS 2. PRACTICE

This paragraph provides an overview of the recommendations for practice resulting from the conducted research.

The construction sector is in a situation that construction activities are increasingly taking place in urban areas. Which results in increased complexity of construction projects and increased impact on the daily lives of the residents of those cities. Investing in innovative logistics now will result in a solution for this increasing complexity before it could potentially negatively impact the sector.

Communication structures

Focus on the communication structure of information from the contractors and suppliers to the operator of a CCC and vice versa. This will reduce the time consumed in the modelling activities. Cost accounting during the preparation stage of a project to predict the impact of including a CCC will be achievable and thereby increasing the use of these innovations in the construction sector.

Transparency

Implementing innovations like the Construction Consolidation Centre requires collaboration and transparency within the supply chain. Costs savings as shown in this research are theoretical and will only lead to actual savings and increased implementation of CCCs if implemented and discussed during the contracting stages.

Investing in input data

Calculating the benefits of the innovations in the research required a benchmark with the traditional process. Investing in infrastructure to enable continues measuring of the construction process to collect this data can help to prove the profitability of innovations. Enabling better use of past case data for the predictions of the impact of including innovations such as Construction Consolidation Centres.

Generic cost data

Building a large database of generic cost data of construction processes for benchmarking requires a lot of resources. Collaboration with companies that are specialised in collecting and managing these databases could be beneficial for the development of costing models in practice.

The previous chapters showed the scientific process of developing a calculation model for predicting the impact of including a Construction Consolidation Centre in a project in the Dutch construction sector. The thesis will be finalized by looking back at the process and outcomes of the research conducted during the last months. This chapter includes a reflection on; the relationship between the research and the graduation theme, the research methodology, the scientific relevance of the research, the applicability of the research outcomes in practice and a personal reflection on the process.

The relationship between the graduation theme and the research.

The research is part of the Design and Construction Management sector of the Management in the Built Environment master. The theme of the research is managing construction logistics for improved environmental and economic performance. The focus of this research was the financial side of the implementation of innovations in construction logistics. In the past years, various students did research on this topic. The research is connected to previous research done by TNO in collaboration with companies involved in the development of Construction Consolidation Centres in the Netherlands. Examples of these companies are Volkerwessels Materieeldienst, Boele & van Eesteren and Dura Vermeer. The model developed in this research proved to be beneficial for the development of these Construction Consolidation Centres.

Research methodology

The aim of this research was to develop a costing model that could predict the impact of implementing a Construction Consolidation Centre in a construction project. The research was structured with five research questions. The first one dedicated to creating a body of knowledge. Three questions dedicated to the input, modelling and the output of the developed model. The final question considers the implementation of the model in practice.

The literature study conducted in this research was clear and structured. The first part of the research was dedicated to literature on the history, characteristics, activities and benefits of CCCs. The second part of the research was focussed on methods for cost accounting in construction logistics. Combining both aspects resulted in a structured starting point for the empirical part of the research.

The initial idea was to test this framework in past cases in which the CCC Utrecht was incorporated. In combination with the results measured in previous research conducted by other students and TNO. In reality, the available data proved to include only small parts of the total activities included in the model. The initial idea to conduct structured interviews to generate the required data in an efficient way changed to semi-structured interviews to find out about the data that was available.

The plan to test the model by applying it in a current case changed from collecting data by conducting interviews to actively participating in extracting the available data by means of action research. Although not initially designed this emerging method resulted in new insight and an iterated model that could generate insight with the limited input generated in this early stage of the Wonderwoods project.

As a last step of the process, the initial idea of testing the model with experts in a panel changed to an only survey of all involved experts in the project. Due to time limitations as a result of the late start of the Wonderwoods project, it was not possible to gather all the involved experts for an expert panel. The results of the survey, however, contribute to a better understanding of the factors included in the model and contributed to advising for the continued development of the model.

11 REFLECTION 2. PERSONAL

I started my graduation period with a strong personal wish to work on a graduation project connected to construction management. In one of the first meetings with Ruben, we discussed the several possibilities within the graduation theme. The selected topic of innovation in construction logistics kickstarted my graduation. It was relatively easy to come up with the initial research proposal based on my own little experience and the expertise of Ruben. During the process this research proposal did not change much it was only expended and developed. I myself, however, needed a lot more knowledge on the topic. Both on the developments within the construction logistics sector as well as on the financial model side. This effort to study on both topics, the delivery of the report, my function in the board of the study association and the other courses I needed to follow resulted in a busy period. During the past period, I had several feedback sessions with Ruben which resulted in a finalized theoretical model.

In the period after p2 the start of my empirical research I met the operator of CCC Utrecht and the project manager of the Wonderwoods project. Showing them the theoretical costing model resulted in tense faces and doubt. This reality check with practice steered my process away from purely theoretical towards a more pragmatic approach. While developing the model based on literature combined with research conducted in previous projects supplied by the CCC Utrecht I validated the process with the operator of the CCC Utrecht. After weeks of trying to get data in a structured manner with the methods, we learn in the university the motivation to continue was at its lowest point. This final push led to the realisation that this research required a different approach. If the data for the ideal case is not available or known to the involved experts than the focus should be on the information that is available. Which parts of the “ideal” model can be used without the information provided by the stakeholders? During the last weeks of the research period, an important meeting for the preparation stage of the Wonderwoods project took place. The operator was asked for the first time to prepare an overview of the costs and benefits upfront instead of communicating prices and measuring during the project. A perfect opportunity to test the developed model in a case with a reality check with the available data. The developed model could be used for parts that had enough input data in combination with averages and standardised modes for transport.

Asking for information that could not be provided during a large part of the research was demoralising at times. It did, however, challenge the way I approached the research. Relying on my skills to deal with this change in plans and performing under more stress and time pressure than initially scheduled resulted in a robust framework that can be tested and used in future projects. A framework to be proud of.

ADDENDUM

Part VI

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A APPENDIX

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